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SALTWATER INTRUSION INVESTIGATION

Santa Clara Valley Water District

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SANTA CLARA VALLEY WATER DISTRICT

SALTWATER INTRUSION INVESTIGATION
IN THE
SANTA CLARA COUNTY BAYLANDS AREA, CALIFORNIA

by

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TABLE OF CONTENTS (continued)

Page

CHAPTER VI. RECOMMENDATIONS 82
General Priorities 82
Other Considerations 83
Recommendations Regarding the Present Salinity Monitoring Program 84
Recommendations Regarding Sampling Procedure 88
Sustaining Investigations and Future Budgeting 89

BIBLIOGRAPHY 91

APPENDICES

Appendix A Standards for the Sealing of Abandoned Wells, Santa Clara County (Abridged), SCVWD Ordinance 75-6 97
Appendix B Standards for the Construction of Wells, Santa Clara County (Abridged), SCVWD Ordinance 75-6 102
Appendix C Glossary of Selected Terms 110
Appendix D English-Metric Equivalents 114
Appendix E Well Numbering System 115

FIGURES

Figure 1 Location Map and Study Area 3
Figure 2 Diagrammatic Geologic Profile Depicting Modes of Occurrence of Groundwater, Palo Alto - Mountain View Area 12
Figure 3 Guadalupe River Channel Profiles 23
Figure 4 Static and "Classical Intrusion" Conditions of Groundwater in Coastal Areas 28
Figure 5 Concept of Injection - Extraction Hydraulic Saltwater Barrier at Palo Alto Bayfront, Upper Aquifer Zone 34
Figure 6 Example Page of Groundwater Level Hydrograph, Upper Aquifer Zone 41
Figure 7 Example Page of Groundwater Level Hydrograph, Lower Aquifer Zone 42
Figure 8 Diagrammatic Interpretation of Saltwater Intrusion South of Alviso 72
Figure 9 Hypothetical Setting for Saltwater Concentration and Mechanism of Intrusion, Palo Alto Bayfront Area 74
Figure 10 Time/Chloride-Content Plot for Well 06S02W06P14 Illustrating Groundwater Degradation by Leaching 76

TABLE OF CONTENTS

Page

CHAPTER I. INTRODUTION AND SUMMARY 1
Introduction 1
  Location of Study 2
  Objectives and Scope 4
Summary and Conclusions 5

CHAPTER II. GROUNDWATER GEOLOGY, WATER QUALITY AND SOILS 9
Groundwater Geology 9
  Regional Groundwater Geology 9
  Groundwater Geology of the Baylands 14
Water Quality 17
  Bases for the Characterization of Water Mineral Quality 17
  Surface Water Mineral Quality 18
  Groundwater Mineral Quality 19
  San Francisco Bay Water Mineral Quality 20
  Tidal Incursion Up Guadalupe River 22
Soils 24

CHAPTER III. SALTWATER INTRUSION INVESTIGATION 27
Technical Background 27
Criteria for Recognition of Saltwater Intrusion 29
History of Saltwater Intrusion 30
Technical Approach to This Study 33
  Basic Data 35
  Construction of Monitoring Wells 43
  Review of Sampling Procedure 46
  Analyses of Data 46

CHAPTER IV. FINDINGS OF THE STUDY 48
Present Area of Intrusion 48
  Upper Aquifer Zone 48
  Lower Aquifer Zone 50
Status of Intrusion 51
  Upper Aquifer Zone 52
  Lower Aquifer Zone 55
Geochemical Aspects of Intrusion 61
Interpretive Mechanism of Intrusion 67
  Upper Aquifer Zone 67
  Upper Aquifer Zone, Saltwater Contamination in the Palo Alto Bayfront 71
  Shallow Aquifer Zone Southeast of Palo Alto 75
  Lower Aquifer Zone 77

CHAPTER V. PERSPECTIVE ON THE FUTURE OF INTRUSION 80

TABLE OF CONTENTS (continued)

Page

TABLES

Table 1 Comparison of Analyses of San Francisco Bay Water and Seawater 21
Table 2 Soil Series Correlation with Geologic Units 25
Table 3 Well Construction Data of Existing Salinity Monitoring Wells 36
Table 4 Example Page of Computer Printout Displaying Water Quality Analyses 40
Table 5 Well Construction Data of Newly Constructed Salinity Monitoring Wells 44
Table 6 Summary Tabulation of Recommended Wells to be Added to Salinity Monitoring Program 86

PLATES
(Bound at back of Report)

Plate 1 General Location and Regional Geologic Map
Plate 2 Land Subsidence and Historic Flowing Artesian Wells Map
Plate 3 Geologic Section A-A’, South of Alviso
Plate 4 Saltwater Intrusion Conditions Circa 1940, Upper Aquifer Zone
Plate 5 Isochlor Map Depicting Conditions of Maximum Intrusion at Sometime Areally, Upper Aquifer Zone
Plate 6 Salinity Monitoring Wells, Santa Clara County Baylands
Plate 7 Present Conditions Isochlor Map of Upper Aquifer Zone
Plate 8 Present Conditions Isochlor Map of Lower Aquifer Zone
Plate 9 Selected Examples of Time/Chloride-Content Plots, Upper Aquifer Zone, Alviso Area
Plate 10 Selected Examples of Time/Chloride-Content and Well Hydrograph Plots, Lower Aquifer Zone, Alviso Area
Plate 11 Selected Examples of Time/Chloride-Content and Well Hydrograph Plots, Lower Aquifer Zone, Palo Alto Area
Plate 12 Trilinear Plot of Selected Well Water Sample Analyses, South of Alviso
Plate 13 Trilinear Plot of Selected Well Water Sample Analyses, South of Alviso
Plate 14 Trilinear Plot of Selected Well Water Sample Analyses Depicting Changes in Percentage Reacting Values, South of Alviso
Plate 15 Trilinear Plot of Selected Well Water Sample Analyses, Palo Alto Bayfront Area
Plate 16 Location Map of Recommended Wells to be Added to Salinity Monitoring Program

CHAPTER I

INTRODUCTION AND SUMMARY

Introduction

Saltwater intrusion is characterized by the movement of saline water into a freshwater aquifer. This potential exists in groundwater basins adjacent to the sea or other bodies of saline water. To varying degrees, saltwater intrusion has occurred in numerous semiarid coastal basins worldwide where groundwater is or has been pumped. Ordinarily, under natural conditions where coastal aquifers come in contact with the ocean, fresh groundwater is discharged into the ocean. As these coastal basins are pumped to meet increasing demands for groundwater, the seaward flow of groundwater has decreased or even reversed, causing seawater to enter and penetrate inland in aquifers. This phenomenon is seawater intrusion (Todd, David K., 1959) (Citing of reference will be made by name of author and date and is referred to in the "Bibliography at the end of the text; selected technical terms are defined in Appendix C, "Glossary of Selected Terms" in back of the report).

Comparison of older mineral analyses of groundwater from wells in the San Francisco bayfront area in Santa Clara and Alameda Counties, some dating back to 1907, with more recent data shows that saltwater intrusion has occurred in one form or another. With much higher groundwater demands after World War II and the continuing occurrence of land subsidence, saltwater intrusion conditions became aggravated as to encompass a substantial area of the baylands.

Contamination or intrusion of saltwater into a freshwater aquifer degrades water for most beneficial uses and, when severe, can render it virtually unusable. This, in effect, decreases the availability of water supply and useable basin storage capacity, leading to limitations on groundwater basin management alternatives. Once freshwater aquifers are rendered useless by a severe case of saltwater contamination or intrusion, it is extremely difficult and costly to reclaim them. Salty water is more corrosive to well casing and thereby inherently has the potential to contaminate other than the aquifer(s) intruded by corroding holes in the well casings and allowing saltwater from the intruded aquifer to enter the well and travel vertically to other aquifers not previously intruded.

Recognizing the problems of saltwater contamination and intrusion and their potential threats, the Santa Clara Valley Water Conservation District (forerunner to the present District) implemented a saltwater intrusion monitoring program in 1958-59. In this program groundwater from about 45 wells was sampled and analyzed for chloride content, a primary indicator of saltwater contamination, on an every-other-month basis. This program continues to the present with some modifications and with the addition of some newly constructed wells. In 1975 two consultants, Arthur J. Inerfield and William C. Ellis, were retained principally to review the monitoring program and data collected (Inerfield, Arthur J. and Ellis, William C., 1975).

This report is the result of investigation of saltwater intrusion initiated by the District in 1973 and is inclusive of the Inerfield and Ellis study and preliminary studies by staff engineering geologists Frank Fenzel in 1973 and James B. Scott in 1977.

Location of Study

The study area is located in Northern Santa Clara Valley adjacent to the southern San Francisco Bay in Santa Clara County, California. The southern limits of the study area are delineated by Bayshore Freeway (U.S. Route 101) and Nimitz Freeway (State Route 17), widening slightly beyond these limits to the northeast and northwest (See Figure 1). The area includes the community of Alviso, northern portions of the Cities of San Jose, Santa Clara, Sunnyvale, Mountain View, an eastern portion of the City of Palo Alto and the western portion of the City of Milpitas. Salt evaporator ponds are located adjacent to much of the Bay in this area and are separated from the Bay and adjacent inland areas by levee systems. Inland from the salt evaporators are vast areas of agricultural, industrial and urban development. Urban land uses include mobile home parks, residential use, sites of sanitary landfill and sewage treatment plants, and parkland.

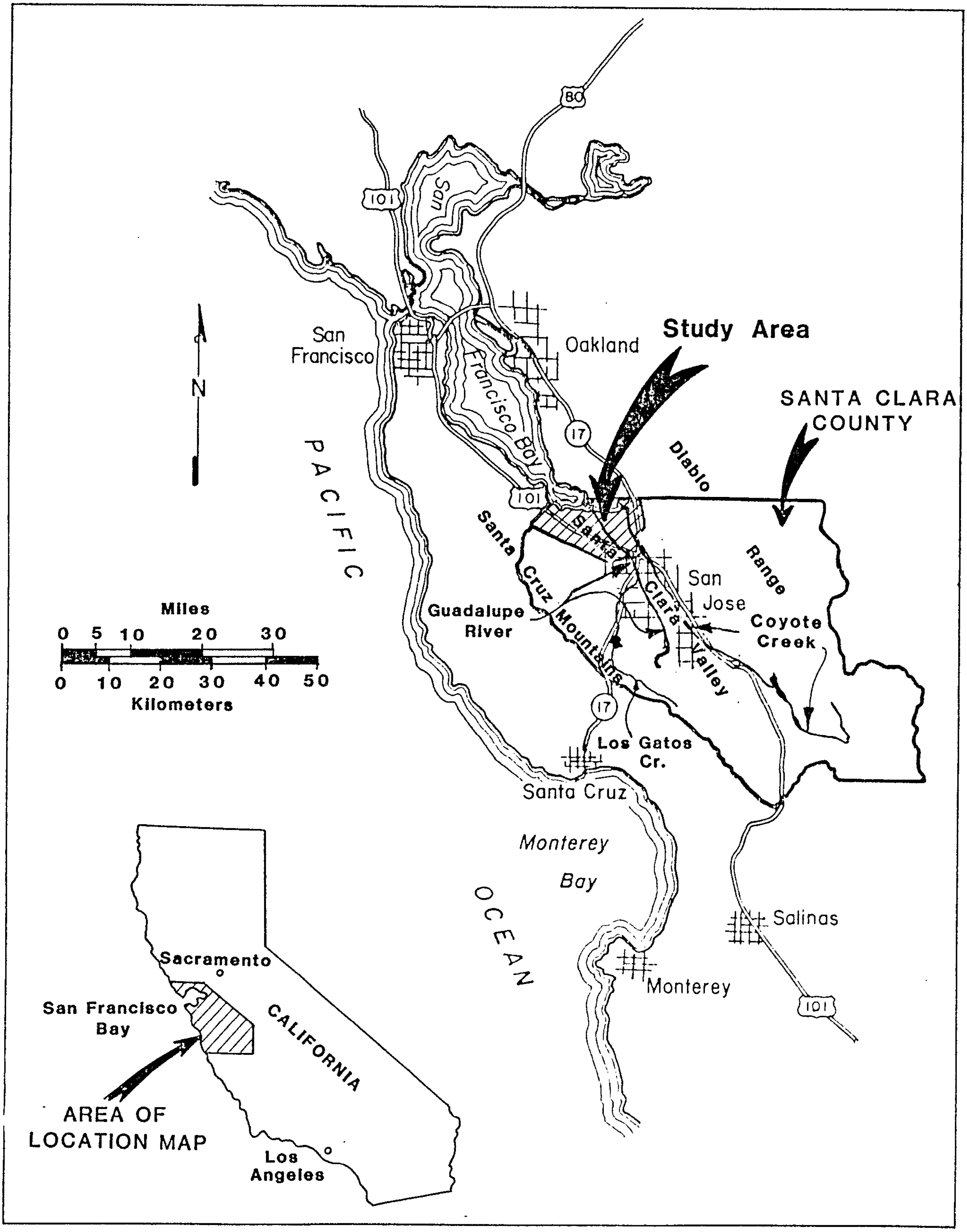


Figure 1 LOCATION MAP AND STUDY AREA

Objectives and Scope

The primary objectives of this investigation are to determine the conditions and mechanisms of saltwater intrusion occurring in aquifers along the Santa Clara County bayfront area so that future courses of action can be planned and implemented, if required, to protect the groundwater basin. In order to meet these objectives, more specific and interim objectives had to be attained. These include the following:

1. Define the areal extent of the saltwater intrusion problem and depths at which it occurs (or aquifers involved) and define the severity of the contamination and intrusion as they presently occur.

2. Review historic mineral analyses for wells with long-term records and ascertain, if possible, an insight upon future trends.

3. Determine the mechanism or the process of saltwater intrusion and the factors that control it in the study area.

4. Determine the mineral characteristics of the mixed or contaminated groundwater (mix of freshwater and seawater) and the geochemical processes involved to effect the resulting quality.

5. Present possible actions required to prevent or minimize any further intrusion.

6. Determine the overall (and individual well) suitability of the current salinity groundwater monitoring program and to make recommendations or changes if warranted.

The objectives of the program were largely met through reviewing available reports and data, evaluating the accumulated data of the salinity monitoring programs, and developing and evaluating additional data from 30 new wells at 20 locations which were constructed as part of this investigation.

This work results in a clearer picture of seawater intrusion in Santa Clara County. This will aid management in determining future courses of action. Such courses of action would fall into two categories: 1) basin management actions which might include controlling of land surface subsidence and water level gradients adjacent to

San Francisco Bay, strict enforcement of existing well construction and sealing of abandoned wells standards, and possible revisions of well standards; and 2) structural measures which might include construction of physical or hydraulic barriers and tide gates and field canvassing, identification, and correction of defective or improperly abandoned wells. These possible future actions will be discussed in Chapter VI., "Recommendations".

Summary and Conclusions

The subsurface section of the Santa Clara Valley basin in the flat baylands areas of south San Francisco Bay consists of a preponderance of clays intercalated with thin aquifers. The aquifers are broadly grouped into two units referred to as the "upper aquifer zone", which usually occurs at depths less than 100 feet, and the "lower aquifer zone" which usually occurs at depths greater than 150 feet and which constitutes the principal pumping zone. Groundwater occurs confined (under pressure) in both aquifers zones but the degree of confinement, though variable, is much less in the upper aquifer zone, leading to a condition of variable leaky confinement in that zone.

Previous and current studies indicate the upper aquifer zone fringing San Francisco Bay is widely intruded by saltwater. The present area of intrusion of the upper aquifer zone, based upon data obtained from 1972 to the present, is shown on Plate 7. Intrusion of the lower aquifer zone is substantially less severe and encompasses a much smaller area than that in the upper aquifer zone. The present area of intrusion within the lower aquifer zone is shown on Plate 8.

The areas of saltwater intrusion shown on Plates 7 and 8 are delineated by a chloride content of 100 mg/l. For the purpose of this report, the figure of 100 mg/l is used as a criterion to indicate definite early stages of saltwater intrusion. It is, however, recognized that the actual threshold between non-affected and intruded water probably is somewhat less than 100 mg/l.

Within the upper aquifer zone at present, the "classical case" of intrusion which occurs by displacement of freshwater by seawater and is indicated by total dissolved salt content over 5,000 mg/l has progressed only a short distance inland from the bayfront, estuaries, or salt evaporator ponds. This intrusion had been induced when pumping of the upper aquifer zone had reversed the hydraulic gradient which had orginally been toward the Bay before pumping occurred. This intruding front is preceded by a large aureole of mixed transition zone water with its outer limit arbitrarily defined by the 100 mg/l chloride line. The mixed transition zone appears to be much larger than that which would normally accompany a classical intrusion front.

The greatest inland intrusion of the mixed transition water occurs along Guadalupe River and Coyote Creek, implying a relationship of intrusion with the tidal saltwaters incurring inland along the stream channels where the greatest abundance of shallow aquifers exists (and, conversely, where there occurs the thinnest clay cap at the surface). The large aureole of mixed transition zone appears to be largely caused by incurring saltwater along the stream leaking through the clay cap into the upper aquifer zone when this zone is pumped. Land surface subsidence has aggravated the condition of intrusion by allowing farther inland incursion of saltwater up the stream channels from the Bay.

More recently developed data have revealed a local area of high salt concentration in the upper aquifer zone in the Palo Alto bayfront area. As these high concentrations are much higher than found in normal seawater, it is speculated that the deteriorated waters are entrapped connate water that had undergone a process of concentration (by evaporation) in the geologic past. This locally concentrated groundwater has, in the historic past, moved inland and has the potential to continue farther inland. It is in this area that the District is constructing a two-mile-long hydraulic barrier in order to prevent farther intrusion and to reclaim portions of the already intruded aquifers.

The lower aquifer zone is only mildly intruded. The intruded area encompasses a much smaller area than that of the upper aquifer zone. Most of the contaminated lower aquifers lie beneath the intruded portion of the upper aquifer zone but, in some places, they lie outside and, in a few instances, they occur as nearly isolated intrusion bodies. The noted areal distribution and the exhibited concentration variability of the saltwater contamination with time imply that the intrusion into the lower aquifer occurred as seasonal slugs of contaminated water that were induced from either the surface or the upper aquifer zone through localized connections. As the clay aquitard between the upper and lower aquifer zones is essentially impermeable, the intrusion into the lower aquifer zone had to occur through improperly constructed, maintained, or abandoned wells.

In the 1960's when the groundwater basin was under the greatest rate of overdraft, the areal extent and relative degree of intrusion in both the upper and lower aquifer zones were slightly greater than it is today. The trend of intrusion at present in most areas appears to be essentially static.

The mineralogical character of the waters within the classical intrusion front area is similar in character to Bay water. It is a sodium chloride type but with total dissolved solids of about 5,000 mg/l. Within the large transition zone of mixed waters, a wide variation in quality occurs, as can be expected. Even where the quality of the unaffected native groundwater is known, the resulting quality of the mix with various concentrations of intruding saltwater is not easily predictable. The prediction is complicated by geochemical changes in the intruding waters brought about by formation materials. The quality of the transition zone groundwater and the geochemical processes involved upon intrusion are further clouded by certain amount of variations in quality of the native groundwater from one location to another (usually in short distances areally). The most obvious and predictable result upon mixing is a higher total dissolved solids and chloride content than that of the native freshwater; the reacting values of all the constituents involved are not proportional as if a simple admixture of the waters involved had resulted. Among the most prominent of the geochemical processes involved appears to be base exchange among the cations and in some instance the solution enrichment of sulfate at the expense of bicarbonate among the anions upon intrusion of sodium chloride water. The rise in reacting values of sulfate upon intrusion was noted in the uppermost aquifers and not noted in the deeper aquifers.

The present status of intrusion is subject to change, depending upon the future basin operation and groundwater demand in the area. The resumption of land surface subsidence is the greatest potential threat to aggravating the intrusion condition as it would further depress the land surface fronting South San Francisco Bay. This would increase the inland hydraulic gradient relative to the classical intrusion front and expose a larger area to intrusion as a consequence of the greater inland incursion of tidal waters. A lowering of the piezometric level in the lower aquifers, which is related to the cause of subsidence, will also increase the potential for intrusion into the lower zone.

At this time the two principal means, based on economic practicality, to prevent or minimize any further intrusion are judicious management of the groundwater basin and strict enforcement of ordinances on well construction and abandonment standards (Appendices A and B). These means, which have been adopted by the District, should continue to be implemented.

CHAPTER II.

GROUNDWATER GEOLOGY, WATER QUALITY AND SOILS

Groundwater Geology

Several comprehensive basinwide groundwater investigations have been performed within North Santa Clara Valley by various investigators and agencies. These are included in the Bibliography. Consequently, this aspect will be discussed here only in a cursory manner. The discussion on the groundwater geology of the local baylands will be discussed in more detail.

Regional Groundwater Geology

As shown on Figure 1, the study area, adjacent to South San Francisco Bay, is located in the central portion of North Santa Clara Valley, which is a large structural depression in the Central Coast Ranges of California. The Valley is filled with alluvial and inland sea deposits washed down from the Santa Cruz Mountains on the west and the Diablo Range on the east. Along the northern boundary of the basin in Santa Clara County, the Valley is approximately sixteen miles wide. The northerly continuation of the basin joins the Niles Cone area of the basin in Alameda County along the east flank of the basin, joins the alluvial plains of San Mateo County along the west flank of the basin and dips beneath South San Francisco Bay in the central portion. North Santa Clara Valley basin becomes narrower to the south-southeast and is connected to South Santa Clara Valley via Coyote Valley and Llagas Basin. Coyote Valley is a tributary subbasin of North Santa Clara Valley and the Llagas Basin is a tributary subbasin of South Santa Clara Valley, with the dividing line of the two subbasins located along a topographic divide at Morgan Hill, 25 miles south of the Bay.

From the elevated edges of the basin, gently sloping alluvial fans of the basin's tributaries laterally merged to form an alluvial apron, descending down to the basin interior. At their distal toes they merge into the basin, tidal and shallow marine deposits of the baylands which fringe southern San Francisco Bay. The interior baylands are essentially a flat plains area with imperceptible slope. Streams tributary to the Bay had cut a pattern of incised meanders on the flat baylands surface. A number of the larger stream channels have been modified (straightened and deepened) by man for flood control purposes. Plate 1 presents the geologic map of the study area, showing the surficial distribution of the predominant geologic units.

The maximum depth to bedrock beneath the valley alluvial fill and sedimentary materials is in excess of 1,500 feet. It is not known whether faults, which occur in the bedrock beneath the valley fill, cut the various upper sedimentary fill layers or have an effect on the water-bearing materials of the basin.

Due to the mechanical sorting of alluvial sediments as they washed in from the mountains, coarser and more permeable deposits are found along the elevated edges while the finer and less permeable deposits are found in the basin interior. The coarse materials (gravel and sand) represent aquifers while the nearly impermeable fines (silt and clay) represent aquitards. Aquifers in the basin interior are stratified within a predominently clayey section while, in the upper elevated edges of the basin, aquitards are generally of limited extent. Since the degree of stratification of aquifers and aquitards varies over different parts of the basin, regional depiction of the basin requires grouping aquifers into generalized hydrographic features. In the elevated upper fan area where material stratification is poor and discontinuous, groundwater occurs as one common, unconfined (water table) groundwater body. This area is referred to as the "forebay" because it is the principal area of basin recharge.

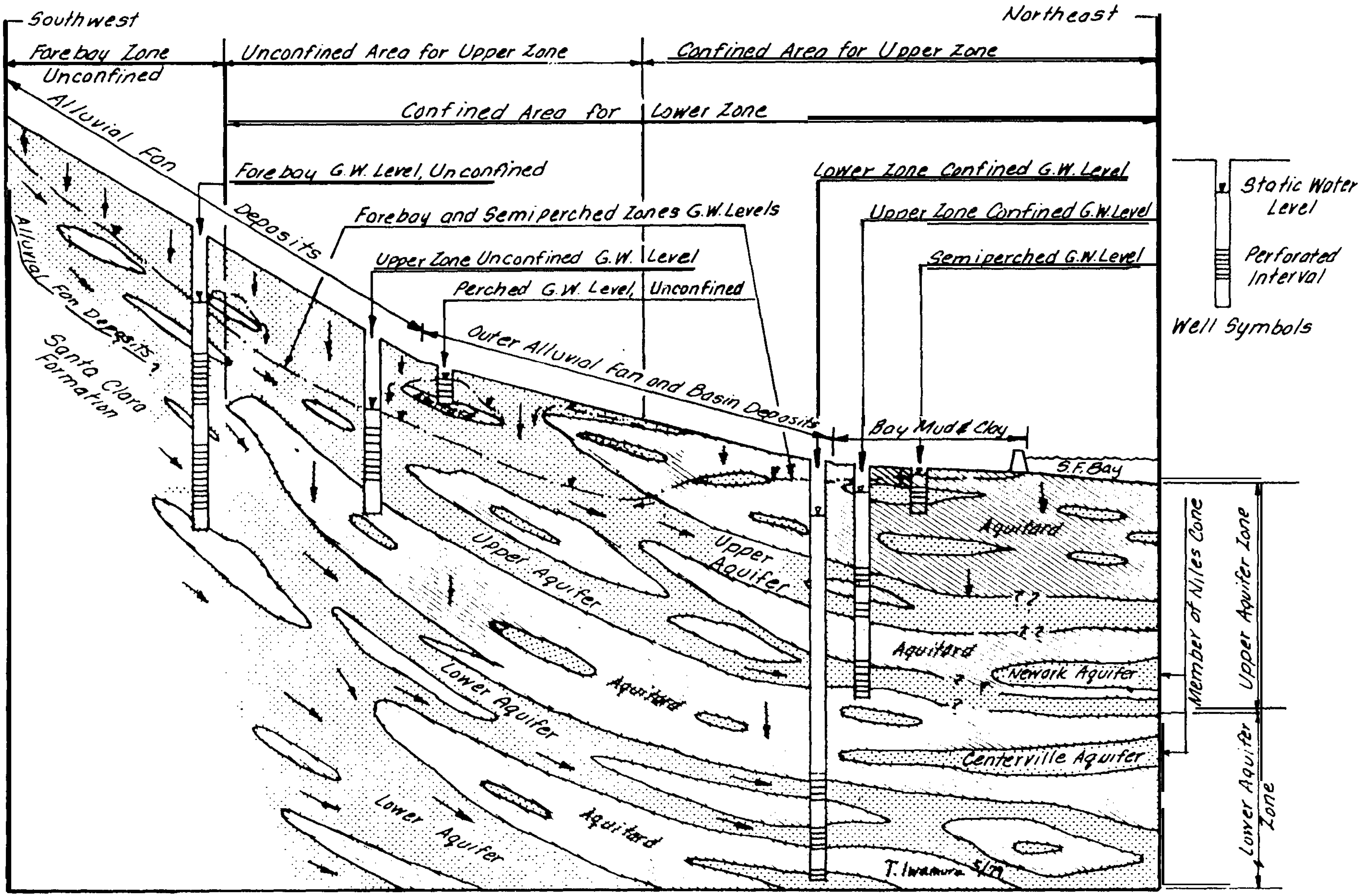
Progressing down the fan, stratification increases, and the common forebay aquifer becomes divided into numerous separate aquifers. For the interior of the basin, these numerous aquifers have been divided into two broad units, the upper aquifer zone and the lower aquifer zone. This division is made on the premise that waters in the lower zone occur confined (under pressure) under an extensive clay aquitard, while in the upper aquifer zone they occur under various modes, from unconfined to confined. Where, in the upper zone, water is confined, the degree of confinement varies from "perfect" to a condition that can be practicably described as leaky confinement. The two broad aquifer zones are effectively separated by an extensive aquitard in the interior portion of the basin at depths of 150 to 250 feet in the mid to lower fan area and 100 to 150 feet in the baylands area. This major confining layer, though ill-defined, pinches out toward the elevated forebay area.

Within the mid-fan and portions of the downstream fan areas, the upper aquifer zone groundwaters are generally unconfined, although portions are under various degrees of local confinement, depending upon the existence and extensiveness of the overlying aquitards. Progressing down to the toe of the fans and into the baylands where there occurs a preponderance of clayey aquitards, upper zone groundwater occur confined in aquifers beneath clay layers and bay muds, though in places the confinement is leaky.

Additionally, within the unconfined portion of the upper zone, locally perched groundwater occurs on restrictively draining clay layers or lenses at random locations. Also within the upper zone in the lower fan and baylands, a large area of semiperched groundwater occurs. Semiperched is referred to groundwater that is perched within the predominantly clay section, but without an unsaturated zone occurring between the perched groundwater and the main groundwater below it. These occur in thin aquifers, usually at depths of ten to twenty feet.

The variations in the occurrence of groundwater within the lower fan and baylands demonstrate the complex geologic and hydrogeologic conditions. Each individual aquifer reflects a different groundwater level as the hydraulic continuity between the aquifers is restricted. A generalized diagrammatic depiction of the various modes of occurrence of groundwater is shown on Figure 2, a profile section from the Palo Alto - Mountain View area to San Francisco Bay.

Recharge to the forebay zone and unconfined portion of the upper zone is by deep percolation from surface sources - - streamflow, rainfall, periodic flooding of streams,



Note: Arrows indicate direction of groundwater movement without regard to quantity.

FIGURE 2. DIAGRAMMATIC GEOLOGIC PROFILE DEPICTING MODES OF OCCURRENCE OF GROUNDWATER, PALO ALTO-MOUNTAIN VIEW AREA

FIGURE 2

and irrigation water applied in excess of evapotranspiration. The confined aquifers of both upper and lower zones are recharged through subsurface flows from the forebay or unconfined zone. Movement of groundwater is generally from the elevated recharging forebay to the basin interior where much of the pumping is occurring.

Recharge to the semiperched zone is also principally from surface sources. It is suspected that in the historic past, before extensive groundwater development occurred, recharge to this zone also occurred upward from the upper confined zone through imperfections in or leakage through the confining aquitards. As such, excess waters to the zone may have discharged into San Francisco Bay through the numerous dendritically patterned drainage systems of the tidal marshlands circumferencing the Bay.

When groundwater was first pumped from the basin, water levels were at shallow depths and unused groundwater from the upper zone discharged into the Bay via the semiperched zone; piezometric pressures within the lower confined zones (and some of the upper confined aquifers) were above land surface in the interior portion of the basin (area shown on Plate 2) and in the area beneath the southern portion of San Francisco Bay (freshwater extended underground far beyond the shore of the Bay). Wells perforated in the lower confined aquifers were flowing artesian wells. This artesian condition indicates that the intervening aquitard separating the upper and lower aquifer zone is quite impervious and prevents the escape of large amounts of water into the upper zone; otherwise the artesian pressure would have naturally dissipated.

In later years, as demands for groundwater increased, the levels were lowered and natural discharges to the Bay from the upper zone essentially ceased; piezometric pressures of the confined waters were lowered to below the land surface and, in some areas, by substantial amounts. Lowering of piezometric pressures within the lower confined zones led to land surface subsidence, a broad, gradual sinking of the surface. Subsidence over the years aggregated to almost thirteen feet in an area a mile southeast of downtown San Jose. In the baylands area, land subsidence aggregated to about four to six feet from 1934 to 1967. This is shown on Plate 2 by a contour map of lines of equal land subsidence. Total subsidence in the area which includes additional subsidence before and after the period 1934 to 1967 would aggregate to a greater amount than that indicated.

As the land subsided to below sea level, levee systems had to be constructed along the bayfront and up along tributary streams. These levees have subsequently inhibited natural surface drainage off adjacent lands requiring drainage waters to be pumped over them. Land subsidence also resulted in further encroachment of saltwater up the mouths of streams which, together with lowered groundwater levels and pressures, contributed to the potential for saltwater intrusion. Significant references on land surface subsidence are Tolman, C. F. and Poland, J. F., 1940; Poland, J. F. and Green, J. H., 1962; and Poland J. F., September 1969.

Groundwater Geology of the Baylands

Based upon inspection and review of available well logs in the baylands area, the aquifer systems beneath the surface probably represent sand and gravel filled stream channels etched into a prevailing clayey surface in past geologic time and subsequently buried by younger sedimentary deposits. As a consequence, these aquifers have the configuration of sinuous paths from the upper-and mid-fan areas through the Valley and to beneath the Bay, with limited lateral continuity. These aquifer characteristics were analyzed by the California State Department of Water Resources who presented the results of their study in "Bulletin No. 118-1" (December 1975). A selected cross section from that report, as modified by this author, is presented as Plate 3.

Earlier studies of well logs by Hogenson, et al. (March 24, 1967) also pointed to the same conclusions and further verified by data collected from monitoring wells constructed for this investigation in 1977 and 1978.

Within the upper zone, the well log analyses indicated a significant number of aquifers beneath the Guadalupe Creek area which represents a major drainage down the thalweg (axial trough) of the Valley. One of the aquifers within this zone has been referred to as the "Agnew 60-Foot Aquifer" in an earlier report (California State Department of Water Resources, 1967). Some of the earlier delineations were modified as part of this study. For an example, a test hole drilled to a depth of 100 feet at the intersection of Lafayette Street and Highway 237 (Test Hole E-1) encountered no significant aquifer where aquifers were presumed, indicating that the western limit of the aquifer system beneath Guadalupe River was east of that point.

Another area where significant groupings of aquifers in the upper zone were reported is beneath Coyote Creek which flows along the east side of the Valley to the Bay. In bayland areas to the east of Coyote Creek, hardly any significant shallow zone aquifers were found. Also, in the bayfront area of the Cities of Santa Clara and Sunnyvale, no significant aquifer systems were found in the upper zone.

In the Palo Alto-Mountain View bayfront area, two relatively thin (three to ten feet thick) aquifers were found in the upper zone. These are referred to as the "20-foot" and "45-foot aquifers" (Jenks and Adamson, Inc., and Brown and Caldwell, Inc., October 1974). These were delineated as a result of test drilling and well construction as part of the Santa Clara Valley Water District's hydraulic saltwater barrier project in Palo Alto. The logs of test holes indicate the aquifers to be variable in depth and thicknesses. The absolute lateral continuity of the two aquifers is not known with certainty. Aquifer performance tests of the two aquifers at Well I-1, located between Palo Alto Municipal Golf Course and Embarcadero Road, opposite Faber Place, indicated vertical hydraulic communication between the two aquifers and with the semiperched zone. The tests showed no hydraulic connection between the 45-foot aquifer and the 185-foot aquifer, the uppermost aquifer in the lower aquifer zone.

Seasonal groundwater level fluctuations (water table condition) in the semiperched groundwater are very small, as expected, because this zone is not pumped. Some level variability in local areas may occur where the semiperched zone is in direct contact with surface water sources such as stream channels or areas where water ponds.

Seasonal fluctuations of piezometric or pressure levels within the upper zone aquifers also are small since only small volumes of water are pumped from this zone. Fluctuations of piezometric levels, caused by atmospheric variation, are also small as the confinement of these upper zone pressure aquifers is not perfect.

Seasonal fluctuations in the lower aquifer zone show wide ranges of pressure responses since this is the principal zone of groundwater pumping. Piezometric levels also respond to changes in atmospheric pressures as the confinement is complete.

The aquifer conditions beneath the southern portion of San Francisco Bay are not well understood, as only a few logs are available in this area. Studies by the California Department of Water Resources (August 1968) in the Fremont, Alameda County area indicate the existence of several fairly well defined confined aquifers beneath South Bay. These aquifers occur in a large hydrographic feature known as the Niles Cone. The Niles Cone is an alluvial fan of Alameda Creek, a major stream which enters the Santa Clara Valley from the east at Niles in Alameda County. The uppermost aquifer in the Niles Cone is referred to as the Newark aquifer which occurs at depths from 60 to 140 feet (upper aquifer zone). From the Fremont area, this aquifer extends outward beneath the Bay to the baylands area of Palo Alto and as far south as Alviso where it feathers out. The usual thickness of this aquifer is from about 20 to 40 feet. Groundwater in this aquifer beneath the Bay has been highly intruded by saltwater.

Another significant Niles Cone aquifer is the Centerville aquifer, which is between 180 and 200 feet in average depth and is often referred to as the "180-foot aquifer". This aquifer is areally as extensive as the Newark aquifer and is separated from it by a significant aquitard zone. It is suspected that the Ravenswood wells in the San Mateo County baylands area and the few wells drilled in the middle of South San Francisco Bay had tapped freshwater from this aquifer.

Other deeper aquifers of the Niles Cone occur beneath the Centerville aquifer, but their areal distribution and character beneath the Bay is not as well defined as the Newark and Centerville aquifers.

The relationship of the Niles Cone aquifers and the aquifers of Santa Clara County is not well understood. It is suspected that they are not directly connected although a small amount of groundwater may transfer between them by leakage.

Water Quality

This section discusses the bases for the characterization of water mineral quality and the general mineral quality of native uncontaminated surface water and groundwater within the study area. This is to serve as a general background and aid in determining whether or not intrusion has occurred. The resulting quality that occurs upon mixing with saltwater will be discussed subsequently in Chapter IV under "Geochemical Aspects of Intrusion".

Bases for the Characterization of Water Mineral Quality

The quality character of waters can be specified in regard to their mineralogical (chemical), physical, sanitary, bacterial and biological properties. For the purposes of this study, the mineralogical character of the waters will be emphasized. The mineralogical character of waters and its quality for use are based upon the principal constituents dissolved in the water and their individual or collective concentrations, in addition to how these may affect some of their other chemical and physical properties.

Concentrations of dissolved salts, either total (total dissolved solids - TDS) or of individual mineral constituents, are expressed by weight in milligrams per litre (mg/l). An indication of total mineral salts is also expressed in specific electrical conductance as micromhos per centimetre (umho/cm) at 25 degrees Celsius. The mineral type of water is based upon the duo naming of predominant cations and anions as measured in reacting values or milliequivalents per litre (me/l). Concentrations of equivalents are used because natural waters are in equilibrium which is achieved by a balance of reacting values of positively charged ions, with calcium, magnesium, sodium, and potassium being the principals, and negatively charged ions with carbonate, bicarbonate, sulfate, and chloride being the principals. The positively charged ions and negatively charged ions combine and dissociate in definite weight ratios. Concentration in milliequivalents per liter for an ion in a sample is derived by dividing its concentration in mg/l by the combining weight (formula weight divided by charge of the ion). Through the action of mixing and geochemical processes, equilibrium is quickly obtained under natural conditions. A more detailed account of the mineral and chemical classification of groundwater and other factors involved, such as pH, alkalinity, hardness, minor constituents, etc. is referenced in Hem, John D., 1970.

A generalized classification of waters as to its suitability for various uses is referenced in California State Department of Water Resources, February 1968, Appendix H, "Water Quality Criteria", and also in Todd, David Keith, 1970.

Surface Water Mineral Quality

Surface waters at times of principal runoff vary from a predominantly calcium-magnesium bicarbonate or magnesium-calcium bicarbonate type to a magnesium bicarbonate or calcium bicarbonate type, depending upon the geology of the individual drainage basin. Several of the smaller streams carry waters that are significantly different, such as San Francisquito Creek water which the data indicate is a mixed-cation bicarbonate type. Total dissolved solids of surface water runoffs generally range from about 170 to 250 mg/l with some of the smaller streams being higher. The calcium carbonate hardness of these waters range from hard (121-180 mg/l) to very hard (greater than 180 mg/l). Nitrate content is usually low, from a trace to less than 10 mg/l. Occasionally, higher readings were noted which imply unnatural influences. Chloride content ranges from 7 mg/l to about 50 mg/l with some occasionally higher readings. During low natural flows of the streams, higher concentrations of constituents are expected because streamflows consist mostly of groundwater emanating from the rocks and soils in the mountainous drainage basins.

When diverse mineralogical types of surface waters mix, a predictable admixture would result in the absence of geochemical processess (chemical interaction with formation materials). Geochemical processess are common in groundwaters.

Groundwater Mineral Quality

The mineral quality of groundwater is a reflection of the quality of surface water and how this water becomes altered as it infiltrates into the ground and percolates along its underground journey. Groundwater quality within the basin can vary widely, depending upon the individual character of the recharging water, geochemical condition within the ground, various modes of occurrences of groundwater within the basin (affecting recharge, dilution and concentration), and upon other factors such as basin operation, land use, and waste disposal practices.

As the recharging streamflow infiltrates into the ground in the elevated forebay and percolates down the fan along its underground journey, its quality changes through geochemical processes. Usually more salts become dissolved and, thereby, the individual constituents and the total dissolved solids content will rise. Total dissolved salt content in the groundwater basin generally ranges from 350 to 500 mg/l with somewhat numerous exceptions rising above 500 mg/l. Chloride content is usually below 50 mg/l. Hardness also increases. In most areas, an increase in the calcium to magnesium ratio of reacting values can be expected as calcium is dissolved from the calcareous soils of the upper fan areas. Most groundwater in the upper and mid-fan areas are a calcium-magnesium bicarbonate type.

As the groundwater percolates farther down the fan to the baylands, the ratio of reacting values of sodium to total cations in solution increases as cation exchange occurs with the ions adsorbed on the clay particles. Normally, calcium and/or magnesium ions in solution replace adsorbed sodium ions on the clay releasing the sodium ions into solution. This process is reversible, depending upon mass differences. The resulting quality of water may also increase slightly in dissolved salts and the waters usually change to a mixed-cation bicarbonate type and then eventually to a sodium bicarbonate type as the water percolates down the fan. Chloride content remains low, below 50mg/l. Due to these various geochemical processes, ratios among the cations and anions can be expected to vary, depending upon the location, source and path of the water.

In general a definite distinction between waters in the upper and lower zones could not be made. However, a distinction could be made (in most instances) between groundwater in the semiperched zone and other groundwaters. Groundwater in the semiperched zone usually has a higher salt content (including chloride) probably caused by degradation from agricultural wastewater, or water applied in excess of evapotranspiration. The higher salt content may also come from salts in the surface soils as a result of surface water discharges, ponding, and concentration by evaporation. In some areas, nitrates are high, in places over 100 mg/l. Known locations where nitrates exceeded 45 mg/l are shown by Webster, D. A., 1972.

Waters in the semiperched zone may vary in type, but more typically they are a mixed-cation bicarbonate type and may range to a mixed-cation chloride type.

Anomalously high concentrations of boron were also noted in local areas within the semiperched zone. These were noted in soil water extracts obtained a few feet beneath the surface along Coyote Creek and Lower Pentencia Creek areas. Concentrations up to 7 mg/l were noted (Brown and Caldwell, Inc., July 1978). In previous studies, high boron content was noted in groundwater of Upper Penitencia Creek fan. It is suspected that the origin of boron in both areas is from either/and/or Alum Rock mineral springs, volcanic formation in the Alum Rock area and rising mineralized waters along the Hayward or related faults.

San Francisco Bay Water Mineral Quality

Samples of San Francisco Bay water taken during the course of various studies show that chloride concentrations in Bay water south of Dumbarton Bridge vary between 10,000 and 17,000 mg/l (Inerfield and Ellis, September, 1975). Analysis of a sample collected in October of 1958 under Dumbarton Bridge is compared with that of typical seawater in Table 1. Although the concentration of constituents is less in Bay water than that of seawater by a factor of 20 percent, the characteristics of the two waters are similar. It must be noted that the quality of Bay water is a function of the quality of

TABLE 1

COMPARISON OF ANALYSES OF SAN FRANCISCO BAY WATER AND SEAWATER

(Inerfield and Ellis, September, 1975)

		Bay Water		Seawater
		me/l	mg/l	mg/l
pH	7.8			
Hardness as $CaCO_3$			4,920	
Alkalinity as $CaCO_3$			150	
Iron			0.1	
Fluoride			1	
TDS by Evaporation			34,380	
Conductivity			37,000 (umhos/cm)	48,000 (umhos/cm)
Boron			3.8	4-5
Carbonate		0	0	0
Bicarbonate		3.0	180	140
Sulfate		4.6	2,200	2,650
Chloride		414	14,700	19,000
Calcium		15.8	315	400
Magnesium		82.6	1,000	1,270
Sodium		365	8,400	10,500
Potassium		9.8	380	380

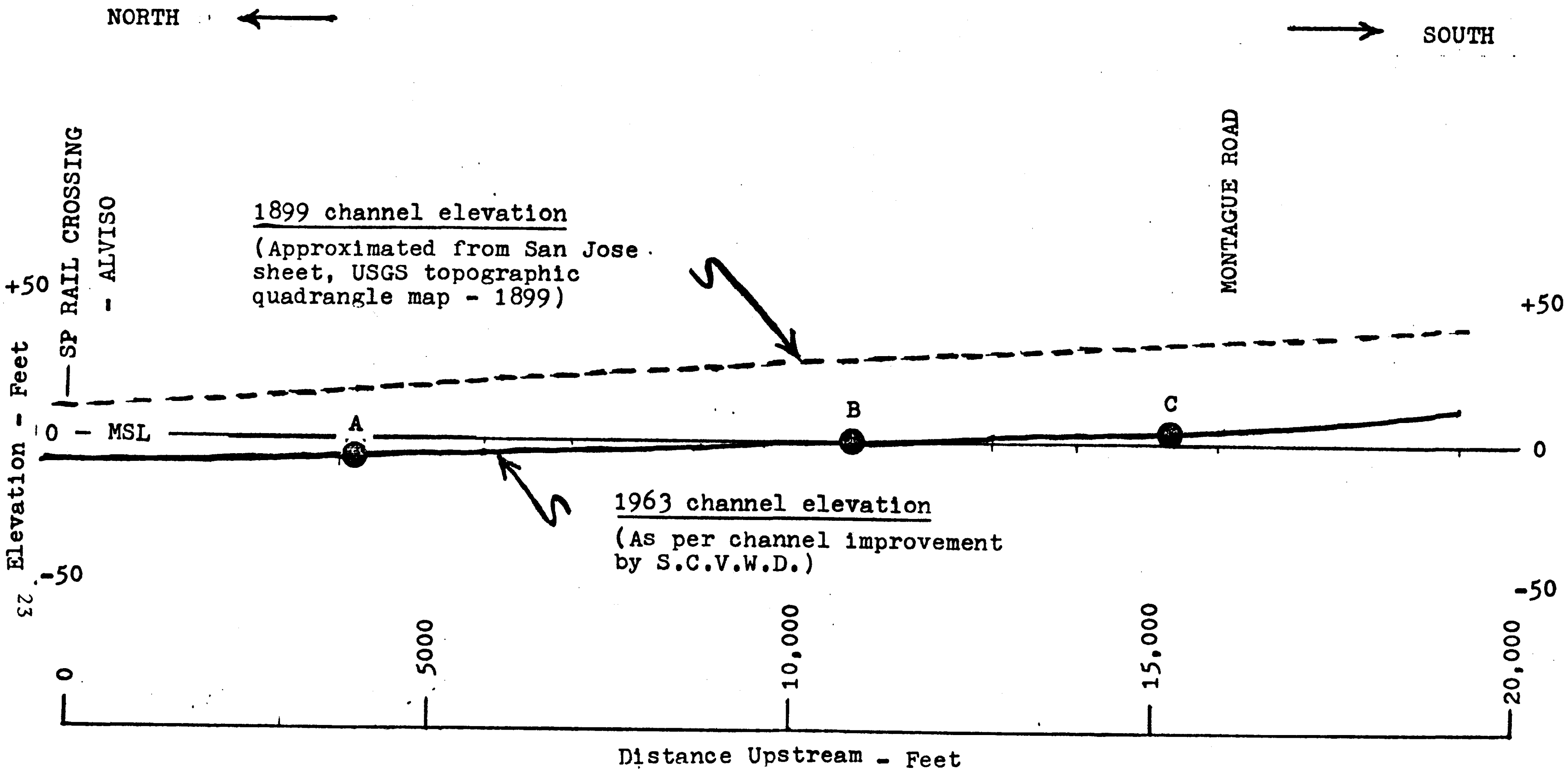
seawater as modified by freshwater inflow to the Bay. Sodium and chloride are by far the predominant ions.

Tidal Incursion Up Guadalupe River

Although inland tidal incursion of Bay waters occurs on all streams entering the Bay, this discussion will be for the Guadalupe River, where tidal incursion has been the greatest and for which the most definitive data are available.

Guadalupe River flows down the axial trough of the basin and, before it enters the Bay, it flows down a broad, flat baylands plain. The occurrence of land surface subsidence and stream channel modifications for flood control purposes have combined to lower the channel, allowing tidal Bay water to incur farther inland. Bay water presently influences the quality of stream water to about Montague Expressway, three miles south of Alviso. An estimate of stream bottom profile changes on Guadalupe River that occurred between 1899 to 1963 is shown on Figure 3, prepared by Inerfield and Ellis (September, 1975). This profile shows that the bottom has been lowered to below sea level in the area south of Alviso. Also shown are the 1964 water sampling locations and chloride content at those locations. Chlorides of 10,300 mg/l was noted 4,000 feet upstream of Alviso; 6,300 mg/l at about 11,000 feet upstream and 570 mg/l just downstream of Montague Expressway. Although the chloride concentrations will vary as the incurring saltwaters are diluted by varying outflows of freshwater, the concentrations indicated reveal the extent of tidal incursion.

Since the profile and chloride content data reflect back to 1963-64, conditions at present may have become further aggravated as land surface subsidence continued to 1969.



1899 channel elevation
(Approximated from San Jose sheet, USGS topographic quadrangle map - 1899)

1963 channel elevation
(As per channel improvement by S.C.V.W.D.)

● Approximate river sampling points, 1964.

A - 10,300 ppm Chloride
B - 6,300 " "
C - 570 " "

Shallow Groundwater Quality
Baylands Investigation

FIGURE 3

GUADALUPE RIVER CHANNEL PROFILES

Horizontal Scale: 1" = 2000'

Arthur J. Inerfield & Assoc.
and
William C. Ellis & Assoc.

The quality of normal winter freshwater runoff through Guadalupe River is usually excellent. A February 8, 1949 analysis of Guadalupe River water taken near the mouth of Almaden Valley indicated the water to be a magnesium-calcium bicarbonate type with a specific conductance of 261 umhos/cm and a chloride content of 8 mg/l. In the baylands area freshwater flows degrade somewhat, particularly during low flow periods when the flow consists primarily of agricultural wastewater returns and effluent seepages from the semiperched groundwater zone. As the freshwater mixes with the incurring saltwater, a normal admixture of the two waters would result as no significant geochemical processes are involved. When the resulting mix degrades to a total dissolved solids content of about 3,000 mg/l, it then is expected to become a sodium chloride type water.

Soils

A soil survey describing soil characteristics as based upon texture, stratification, drainage, fertility and suitability for agricultural and other uses was performed by the U.S. Department of Agriculture, Soil Conservation Service, in Cooperation with Santa Clara County. Soils survey mapping was performed on aerial photographs and soils descriptions were noted in their report dated August 15, 1968.

The soils survey is limited to the upper sixty inches of the surface. Soils developed in alluvial geomorphic settings bears a reflection of the types, sizes and distributions of detrital materials from which they are developed. Soils developed upon upper and middle alluvial fan surfaces are usually coarse to medium grained and generally have good surface and subsurface drainage properties. Soils in the flat plains of the bayland (interfluvial basin deposits) are predominantly fine to medimum grained and have poor surface and subsurface drainage, low permeability,and a high water table (one to five feet in depth). Within this flat baylands areas, however, areas of better drainage and higher permeability do occur along some of the stream channels as they cut through the baylands. Table 2 compares the soils series to the geologic units as shown on Plate 1.

TABLE 2

SOIL SERIES CORRELATION WITH GEOLOGIC UNITS

Geologic Formation	Soil Series	Soil Salinity
Interfluvial Basin Deposits	Sunnyvale silty clay	None to low
	Willow clay	Low to high
	Bayshore clay loam, gravelly loam	None
Alluvial Fan Deposits		
Young	Yolo silty and clay loam	None
	Garretson loam or gravelly loam	None
	Cortina loam, sandy loam	None
Old	Clear Lake clay	None
	Castro clay	None
	Campbell silty clay loam	None
	Pacheco clay and loam	None
	Pleasanton loam, gravelly loam	None
	San Ysidro loam	None
	Arbuckle gravelly loam	None
	Cropley clay	None
	Rincon clay loam	None
Older Bay Mud	Alviso clay	High
(Tidal Marsh)	Tidal Marsh	High

NOTES:

1) Refer to Plate 1 for general areal occurrence of the geologic units.

2) Soils correlation is based upon U. S. Department of Agriculture, August 15, 1968 report "Soils of Santa Clara County".

Table 2 also lists the general salinity characteristics of the various soil series. Among the soils that have high salinity are those adjacent to saltwater bodies. These include the Alviso clay, Tidal Marsh and Willow clay. As based upon available data, the highest salt content noted in a soil-water extract sampled was from the Milpitas Golf Course, which indicated a specific conductance of 18,760 umho/cm and a chloride content of 4,700 mg/l (Brown and Caldwell, July 1978). The extract sample was a sodium chloride type water. Soils at this golf course are afflicted by tidal incursions up Coyote and Lower Penitencia Creeks.

Other soil series, such as the Sunnyvale series, contain varying degrees of salinity. These are a result of other conditions that favor salt accumulation, such as poor surface and subsurface drainage and high water table. In these areas the salts are brought to the surface by capillary action during dry periods, concentrated by evaporation and then are leached down during the wetter climatic cycle.

Many areas in the baylands are afflicted by salinity, but some are not, even where conditions appear favorable for salt accumulation. The absence of soil salinity in these areas is suspected to be due to periodic freshwater flooding, in prehistoric and early historic times, causing salts to be flushed or leached from the surface. It could also be leached from the surface by irrigation, as lands were reclaimed for agricultural development, with or without the use of soil amendments.

CHAPTER III.

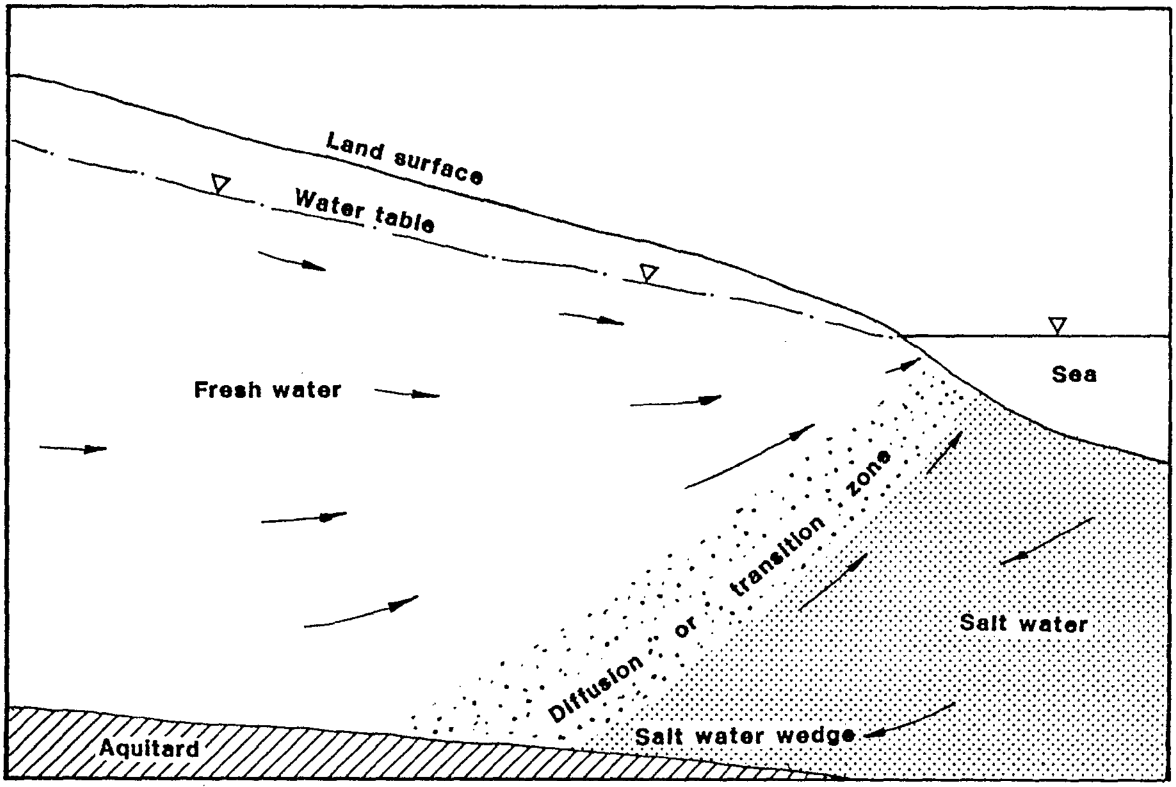
SALTWATER INTRUSION INVESTIGATION

Technical Background

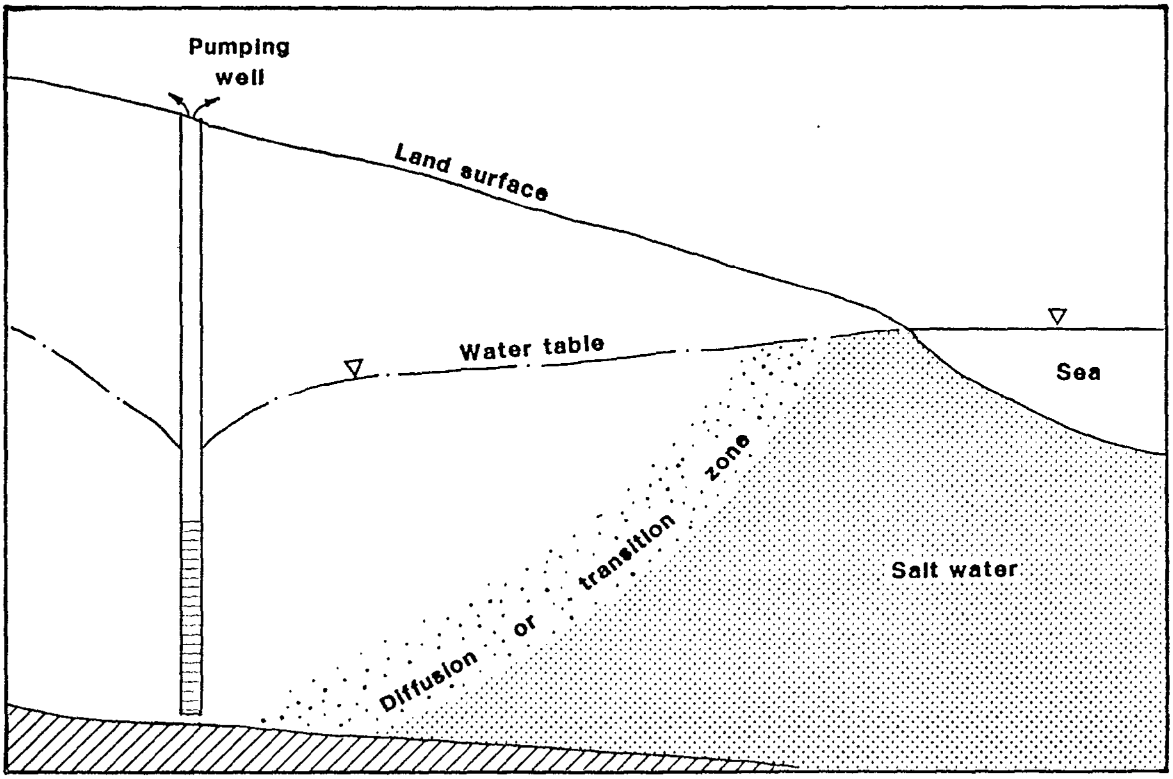
In coastal basins, saltwater intrusion is the encroachment of seawater landward as a body displacing freshwater. It can occur in confined or unconfined aquifers, and can be either temporary or permanent. This intrusion can result from a reversal of hydraulic gradient caused by pumping and basin overdraft which allows saline water to move inland in the underground where freshwater existed before. Destruction of natural barriers that formerly prevented movement of saltwater is another mechanism of intrusion.

In thick aquifers where intrusion has occurred or is occurring, the interface of the saltwater and freshwater forms an intruding front that slopes inland, with the saltwater extending farther inland at the bottom of the aquifer than at the top. This intruding saltwater section configuration is referred to as a saltwater wedge and represents a "classical" example (hereafter will be referred to the "classical case of saltwater intrusion") which is due to the higher density of saltwater compared to freshwater (1.075 g/cm^3 versus 1.000 g/cm^3, respectively). A depiction of the classical case is shown on Figure 4.

Since freshwater and saltwater are miscible fluids in contact, the interface is not sharply defined but becomes a zone or transitional boundary representing a mix of the two waters. This is also depicted on Figure 4. The mixed waters, referred to as the "transition zone" or "zone of diffusion", also reflects a transitional density. The formation, definition and control of the transition zone are affected by hydrodynamic dispersion, which is the mass transfer of salty water displacing and mechanical mixing with freshwater and by ionic diffusion, a chemical diffusion process, which is slower than the dispersion mechanism and imparts a smaller role to the process. The development or growth of the transition zone depends upon dynamic conditions which cause ebb and flow of the interface. Dynamic conditions include extraction of freshwater, variability



A. Balance between fresh water and salt water in coastal aquifer in which the interface is static (largely after Hilton H. Cooper Jr., 1964).



B. Salt water - fresh water interface is advancing inland in response to hydraulic gradient reversal , causing intrusion.

FIGURE 4. STATIC AND "CLASSICAL INTRUSION" CONDITIONS OF GROUNDWATER IN COASTAL AREAS

of recharge and tidal level fluctuations. Steady or static conditions minimize the transition zone thickness and mixing of the waters. Another factor controlling the extent of the transition zone is the physical structure of the aquifer. In the classical case of an intruding front, the transition zone thickness usually ranges from a few feet in undeveloped sandy aquifers to hundreds of feet in over-pumped, highly permeable aquifers (Todd, David K. March 1974).

The range in the mix as to define a transition zone varies among different investigators but can be from 99 percent freshwater to 99 percent saltwater.

The relationship of saltwater to fresh groundwater is discussed in considerable detail in Cooper, Hilton H., et al., 1964.

From a mineralogical standpoint and by definition of saltwater intrusion, three basic components are involved which are 1) fresh groundwater, 2) intruding seawater, and 3) the aquifer material, all coming together and interacting. The resulting mixed waters usually do not result in a simple chemical admixture of the two. Chemical interaction with the formation materials results in often complex geochemical processes involving reversible chemical reactions which occur rapidly to equilibrium. The most common of the geochemical processes include 1) adsorption and desorption of cations and anions on the surfaces of formation materials (ion exchange); 2) oxidation or reduction (including sulfate reduction) and hydrolysis reactions of certain metals; and 3) solution and deposition of carbonate minerals.

A detailed account of the various geochemical processes is covered in John D. Hem (1970).

Criteria for Recognition of Saltwater Intrusion

Although the mineralogical composition of seawater differs widely from groundwater, recognizing the onset of intrusion or predicting the chemical composition of transition zone waters are not simple. Variability within the fresh groundwater from one location to another, geochemical processes, as well as modifications that seawater may undergo while passing through the ground or through marine and estuarine sediments all contribute to the difficulty.

Of all the major ions in seawater, only chloride is unaffected by processes of modification. Chloride is the dominant ion in seawater and, as discussed in Chapter II under "Water Quality", plays only a minor role in groundwater. Hence, an increase in chloride content is the most reliable indicator of the first stages of saltwater intrusion (Revelle, Roger, 1941). A small increase in chlorides may, however, be due simply to a temporary increase in the total dissolved salts and thus may be of no diagnostic significance (Revelle, 1941).

For purpose of this report and as based on previous studies (including Tolman and Poland, 1940), a chloride content of 100 mg/l is used as the criterion to indicate definite early stages of saltwater intrusion. It is, however, recognized that the actual threshold between nonaffected and mixed waters probably is somewhat less than 100 mg/l.

Other methods have been attempted to define early stages of intrusion such as comparing ion concentration ratios and trilinear plots involving the reacting values of all the major cations and anions. These methods have met only varied success as they proved satisfactory only in specific instances and can not be uniformly applied. Attempted applications of these methods are further discussed under "Findings of the Study".

History of Saltwater Intrusion

In the report, "Ground-water, Salt-water Infiltration, and Ground-Surface Recession in Santa Clara Valley, Santa Clara County, California", C. F. Tolman and J. F. Poland (1940) cite the reference, J. P. Mitchell (1910), Standford University, which documents early water quality analysis of groundwater from wells near the Palo Alto bayfront area. The following paragraph is quoted from Tolman and Poland's report under "Salt-water Contamination", page 28:

> In 1907-08, Mitchell analyzed samples of surface water and samples from 12 deep wells close to the Bay. Only one of these samples, the chloride content of which was 228 parts per million, showed local salt-water contamination, and the remainder were low in chloride. Omitting the three highest chloride-values, the range for the wells was from 15 to 40 parts per million chloride. Water from the well nearest the Bay contained only 27 parts per million chloride; this same well in 1929 contained 3,000 parts per million chlorides.

Tolman and Poland went on to mention that by 1920 salt contaminated waters were found in wells near the Bay east of Palo Alto as heavy drafts in the area led to a decline in artesian head. By 1928 conditions had become so serious that various conferences were held to study the situation. It was decided that the long line of artesian wells (Ravenswood wells in the San Mateo County Bay tidelands) dug by the Spring Valley Water Company in 1904 had to be filled and sealed. The location of these wells is shown in California Department of Water Resources (August 1968) Appendix B. These had been left uncapped, their casings had rusted, and at high tide saltwater had entered many of the wells.

Since 1929 some wells near the Bay had been sampled intermittently by Stanford University students, and in the late 1930's the well inspector of Santa Clara County and engineers of the Federal Land Bank took systematic samples from wells on each side of the Bay. From these data, Tolman and Poland outlined the area of saltwater intrusion on a map using the 100 mg/l chloride content as their criterion. A larger scale redrawing of this map is presented as Plate 4. At that time the intrusion was still confined to an area fringing the Bay with the greatest inland intrusion located in southeastern Palo Alto. Tolman and Poland concluded that the main source of contamination was movement of saltwater through abandoned wells within the bayfront. Their studies also showed contamination extended farthest inland in the gravel deposits of streams discharging into the Bay. This indicated that shallow gravels below and contiguous to the present stream channels constituted a second means for encroachment of saltwater as groundwater levels were lowered. Also mentioned was contamination attributed to breaking of the clay seal during construction of Dumbarton Bridge and the Hetch Hetchy pipeline crossing of the Bay. This last conclusion has not been checked, although they mentioned that some wells near the Bay became contaminated a few years after construction of these projects. Severe contamination was restricted chiefly to gravels within the top 100 feet of the ground surface as there occurs a prevalent clay layer beneath them, which is usually found in the zone from 60 to 170 feet below sea level. This layer acts as an impervious barrier against downward movement of saltwater. A large number of wells pierce this clay layer and many of these wells (old wells) may be perforated in both the upper contaminated zone and the lower originally uncontaminated zone, and thus enabled contaminated zone water to migrate downward into the lower zone through the well casing. Damaged casings can also cause interaquifer transfer. Tolman and Poland made strong recommendations to correct interaquifer groundwater transfer by locating culprit wells and repairing, correcting, or sealing them.

Subsequent groundwater studies and reports mention the occurrence of saltwater intrusion along the bayfront, but they treated the subject in only a cursory manner. Unpublished memorandums and letters mention numerous wells in the bayfront that were put out of service due to waters becoming salty.

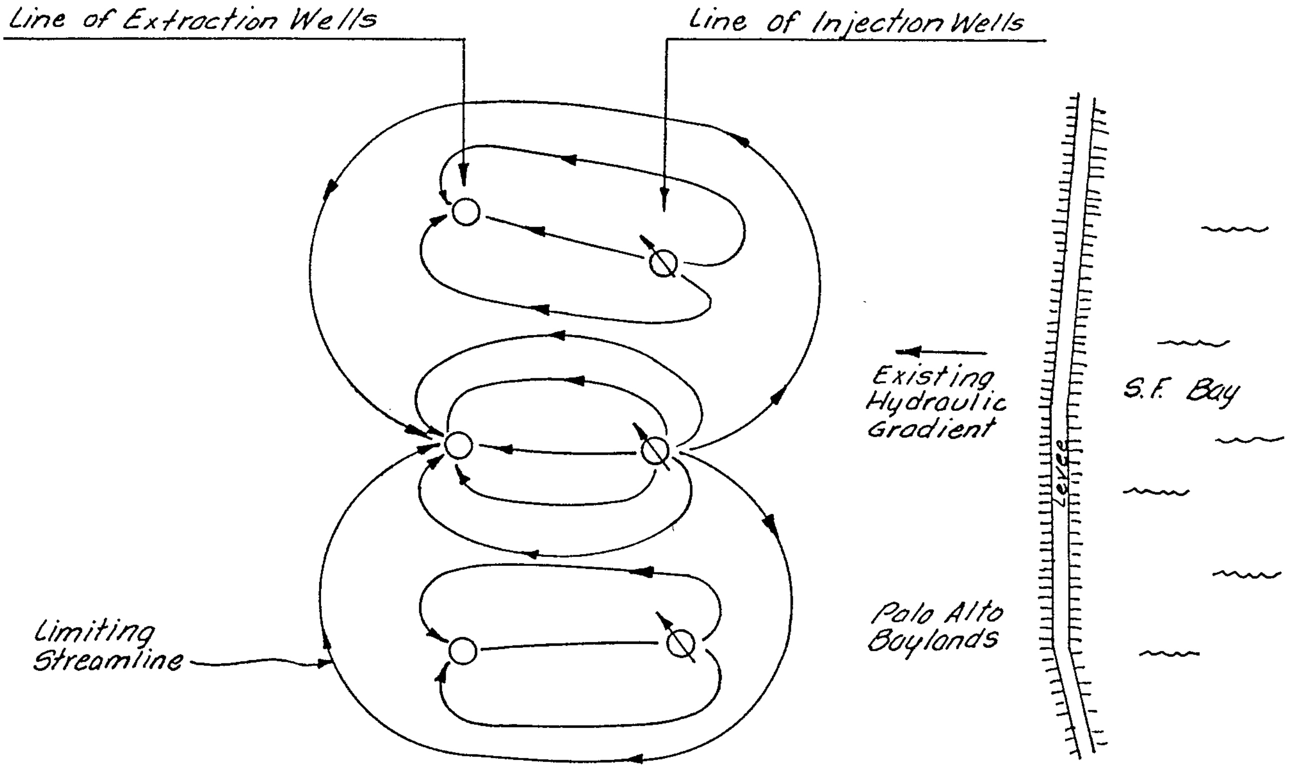
As mentioned in the "Introduction", the District initiated a salinity monitoring program in 1958-59, which was reviewed by Inerfield and Ellis in 1975. Inerfield and Ellis, using available data produced an isochlor map (lines of equal chloride concentration) of the upper zone (0 to 150-feet depth zone), but without regard to a specific instance of time. This map is presented as Plate 5. The 100 mg/l chloride line essentially outlines the maximum known limit of intrusion at one time or another. This map is suspected to reasonably represent conditions as they were in the 1960's when many of the wells were most severely affected by saltwater.

In 1972 the District investigated the feasibility of constructing a hydraulic barrier ("artificial" control of groundwater levels) in the Palo Alto bayfront area. The concept was to construct injection and extraction wells and to operate them in such a way as to create favorable hydraulic gradients to prevent intrusion in the shallow zone and to reclaim the already intruded inland portions of these aquifers. Reclaimed wastewater is to be used to create the barrier and the already intruded saltwater is to be pumped out of the aquifers (Jenks and Adamson, Inc. and Santa Clara County Flood Control and Water District, 1973). This project was studied in more detail in 1974 (Jenks and Adamson, Inc. and Brown and Caldwell, Inc., October 1974) and the project is presently under construction. The concept of the barrier is depicted diagrammatically on Figure 5. A summary of the findings of these investigations leading to the conception of the project are discussed in this report. Certain aspects of the geohydrologic and water quality aspects of this project are also being investigated by the Engineering Department at Stanford University and by the U.S. Geological Suvey.

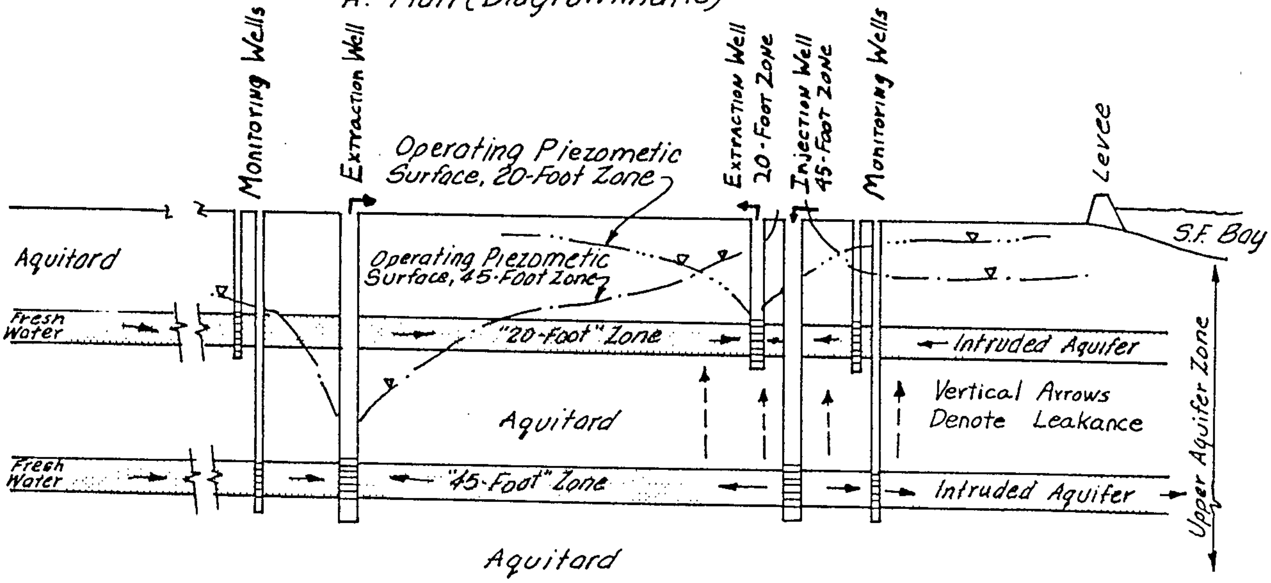
Saltwater intrusion has also been studied in the Niles Cone area of the Santa Clara Valley basin in southern Alameda County where the intrusion problem is more acute (California Department of Water Resources, November 1958, December 1960, June 1964 and August 1968).

Technical Approach to This Study

The geologic setting beneath the baylands is not ideal for the classical case of seawater intrusion discussed previously in this chapter under "Technical Background". Well log data indicated that individual aquifers in the baylands are usually thin, have limited lateral continuity and are sinuous. As these thin, sinuous aquifers are stressed by pumping, their hydrodynamic reactions are expected to be quite different than within thick coastal plains aquifers with large lateral continuity. Furthermore, the series of aquifers beneath the Bay are blanketed (and interbedded) by a series of restrictively permeable clay beds. This is unlike many coastal basins where aquifers may be exposed to the sea in the absence of a clay blanket or on the walls of a submarine canyon or seacliff. As will be pointed out later, the mixed aureole transition zone in the baylands extends several miles inland, with a condition of relatively low concentrations of



A. Plan (Diagrammatic)



B. Profile (diagrammatic, enlarged from general scale of plan)

FIGURE 5. CONCEPT OF INJECTION-EXTRACTION HYDRAULIC SALT WATER BARRIER AT PALO ALTO BAYFRONT, UPPER AQUIFER ZONE

seawater in the mix. This contrasts with a transition zone thickness of only several hundreds of feet in the classical type intrusion. All these differences indicate intrusion process that might be quite different from that of the classical case. The technical approach to the study, therefore, had to be planned to consider a variety of possible mechanisms of saltwater intrusion.

Basic Data

In order to qualify water quality data for purposes of correlation and interpretation, well construction data had to be ascertained for wells that were sampled. Table 3 lists well construction and sampling period for wells currently on the District's saltwater intrusion monitoring program. The well numbering system used is based upon the well's location in respect to township, range and section subdivisions of the Federal Land Survey and is referred to in Appendix E. Plate 6 shows the locations of these wells. For analyses used from other wells, individual searches had to be performed to ascertain well construction data.

As part of the basin-wide groundwater quality monitoring program, all available groundwater quality data acquired by the District and other agencies, including those on past monitoring programs and individual "spot" analyses, were coded for computer storage. For numerous wells, repetitive data were secured and these are listed in chronological order under the particular well number in the printout sheets. An example computer printout page listing is presented as Table 4.

Groundwater level hydrographs for wells on the level monitoring program were similarly prepared by computer coding, storage and printout. Examples of a ten-year portion of a hydrograph printout are presented as Figures 6 and 7, the first shows general characteristics for responses of the upper aquifer zone and the second of the lower aquifer zone. The depth and elevation are in feet.

No surface water quality monitoring station, where repetitive samples have been obtained, is located along stream courses within the baylands. Several partial and complete analyses on a one-time basis are available from various special studies projects.

TABLE 3

WELL CONSTRUCTION DATA OF EXISTING SALINITY MONITORING WELLS

Well Number	Other No. (if any)	Ground Elev. (in ft., approx.)	Well Depth (in ft.)	Perforated Interval (depth in ft.)	Period of Record - Cl Anal. First Date	to Last Date
05S01W22A01		3	prob. greater than 100	-	6-6-61	Present
05S01W35F01		5	250 or 280	-	5-24-74	Present
06S01W01F01		13	297	-	4-8-74	Present
06S01W02N02		4	555	-	1961	Present
06S01W10G03		2	280	-	4-8-74	Present
06S01W11B01		7	208	-	8-29-56	Present
06S01W11N03		6	150	-	4-8-74	Present
06S01W11P01		12	575	-	5-12-49	Present
06S01W12K01			150	-	4-8-74	11-17-76
06S01W12M03		16	125	-	4-8-74	Present
06S01W14E02			prob. greater than 100	-	7- -61	Present
06S01W14L02		13	280	-	7- -61	Present
06S01W14L04		13	90	-	5-11-49	Present
06S01W14M02		11	265	-	7- -61	Present

TABLE 3 (continued)

WELL CONSTRUCTION DATA OF EXISTING SALINITY MONITORING WELLS

Well Number	Other No. (if any)	Ground Elev. (in ft., approx.)	Well Depth (in ft.)	Perforated Interval (depth in ft.)	Period of Record - Cl Anal. First Date	to Last Date
06S01W14P01			280	-	4-8-74	Present
06S01W15G01		8	60	-	6-14-61	Present
06S01W15H01		11	392	-	8- -59	Present
06S01W15J01			Prob. greater than 100	-	9- -61	9-22-77
06S01W15P01			300	-	7- -61	7-29-75
06S01W16E01			425	-	6-14-61	Present
06S01W18J01		9	700	-	5-24-74	7-27-77
06S01W22L04		20	87	-	4-8-74	Present
06S01W23C01		19	728	-	9- -61	Present
06S01W23G02			400	-	7- -61	7-27-77
06S01W24F01			130	-	5-11-49	7- -75
06S01W24N01		24	75	-	4-8-74	Present
06S01W25L01		35	218	-	4-8-74	Present
06S01W25E05		24	Prob. greater than 100	-	3-26-75	11-18-76

TABLE 3 (continued)

WELL CONSTRUCTION DATA OF EXISTING SALINITY MONITORING WELLS

Well Number	Other No. (if any)	Ground Elev. (in ft., approx.)	Well Depth (in ft.)	Perforated Interval (depth in ft.)	Period of Record - Cl Anal. First Date	to	Last Date
06S01W26A02			95	-	4-8-74		Present
06S02W06E10			Prob. greater than 100	-	4-8-74		Present
06S02W06P14		17	16	-	4-8-74		Present
06S02W07L10		25	13	-	4-8-74		Present
06S02W08K01		12	60	-	4-8-74		Present
06S02W09N11			66	-	4-8-74		Present
06S02W09Q01		11	600	-	8- -59		7-27-77
06S02W09R04		11	60	-	5-24-74		9-27-77
06S02W09R07		11	Prob. greater than 100	-	4-8-74		Present
06S02W10Q03		14	637	-	5-28-75		
06S02W16A22			68	-	4-8-74		Present
06S02W17L03		35	122	-	4-8-74		Present
06S02W23D02		45	120	-	4-8-74		Present
06S03W01C11		24	25	-	4-8-74		Present

TABLE 3 (continued)

WELL CONSTRUCTION DATA OF EXISTING SALINITY MONITORING WELLS

Well Number	Other No. (if any)	Ground Elev. (in ft., approx.)	Well Depth (in ft.)	Perforated Interval (depth in ft.)	Period of Record - Cl Anal. First Date	to	Last Date
06S03W02J10		43	46	-	4-8-74		Present

NOTE: Refer to Plate 6 for location of monitoring wells.

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                                                                   01/11/78       PAGE 106

DATE     DO  FLD EC  PH      Q   DEPTH LAB NO.                                                       F   TURB    TH   SAMP
TIME   TEMP  LAB EC  PH     G.H.  SAT   SI02       CA      MG      NA      K  HCO3  CO3    SO4    CL   NO3   B     TDS   LAB

       DWR CENTRAL DISTRICT    20902  06S/01W-15E04 M      43              CONTINUED
 *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

9-00-61                     SC0787                                                                                    2400
                                                                                              24

9-00-62                     SC0788                                                                                    2400
                                                                                              29

8-00-63                     SC0789                                                                                    2400
                                                                                              27

                              06S/01W-15F01 M      43
 *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

5-12-49                       4887                                                                                    5050
 1230                                                                                         30                 310  1919

8-15-49                       4888                                                                                    5050
 1115  68  F                                                                                  20                 260  1919

9-24-52                       5363                                                                  0.0          144  5050
       68  F    469  7.9       21         41      10      52    1.0  241   0     26         20     9.8  0.31     300  5000

                              06S/01W-15F02 M      43
 *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

5-16-49                       4891                                                                                    5050
 1330                                                                                        408                1600  1919

5-23-49                       4890                                                                               940  5050
       60.5F   2325  8.0                 183     117     219         538         344        403      0   0.17         1919

8-15-49                       4889                                                                                    5050
 1125  61  F                                                                                 470                1700  1919

                              06S/01W-15G01 M      43
 *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

6-14-61                     SC0452                                                                                    2400
                                                                                             392

6-20-61                     SC0453                                                                                    2400
                                                                                             395

7-00-61                     SC0454                                                                                    2400
                                                                                             415

9-00-61                     SC0455                                                                                    2400
                                                                                             420
```

Table 4: EXAMPLE PAGE OF COMPUTER PRINTOUT DISPLAYING WATER QUALITY ANALYSES

SANTA CLARA VALLEY WATER DISTRICT

WELL NUMBER: 6S 1W15Q01
PROPERTY OWNER: A.S. CHINCHEN
DISTRICT NUMBER: 643
X COORDINATE: 1577000
Y COORDINATE: 333200
GROUND ELEVATION: 10.
WELL DEPTH: 60.

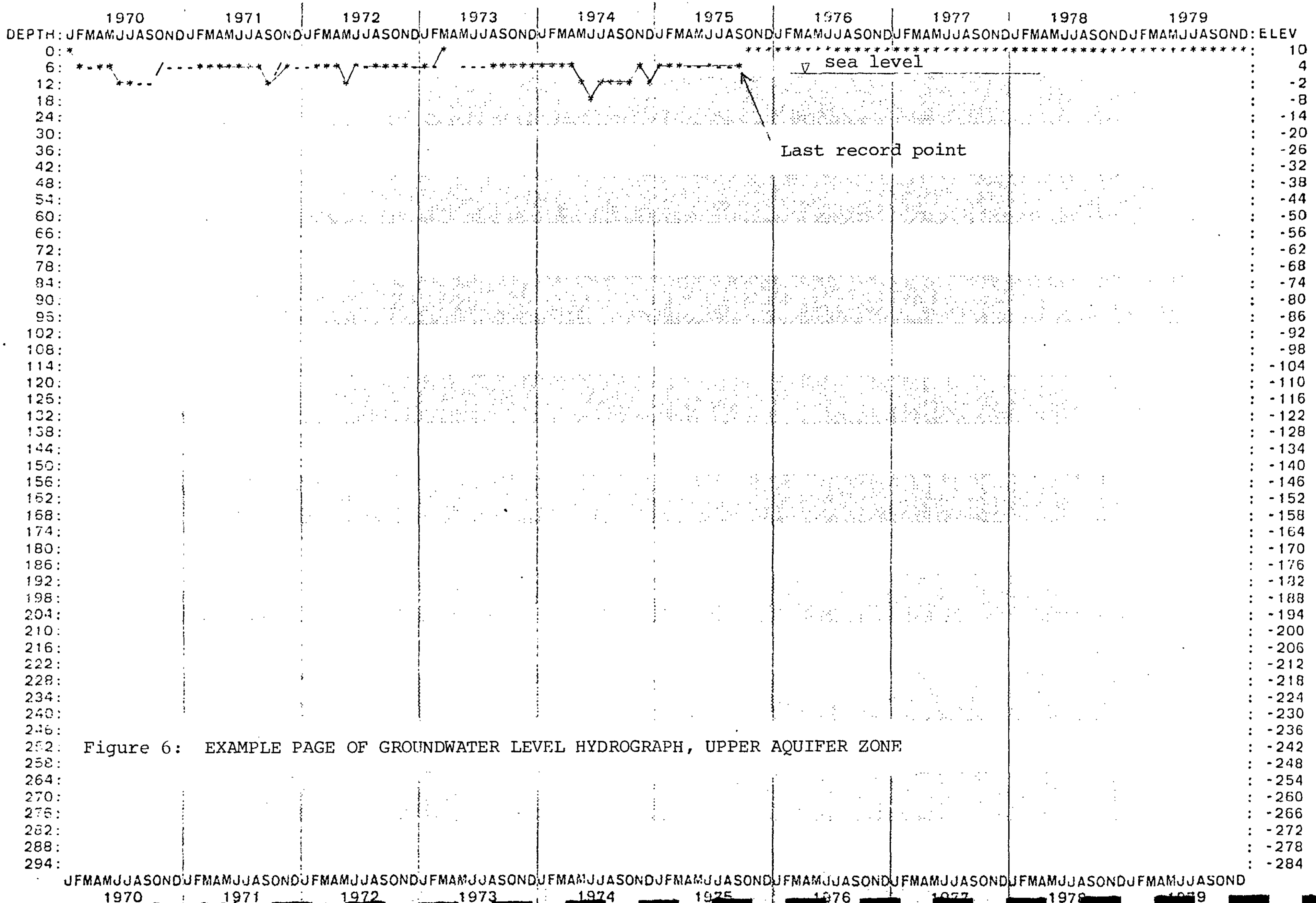


Figure 6: EXAMPLE PAGE OF GROUNDWATER LEVEL HYDROGRAPH, UPPER AQUIFER ZONE

Figure 6

SANTA CLARA VALLEY WATER DISTRICT

WELL NUMBER: 6S 1W15H01
PROPERTY OWNER: A FRENCH
DISTRICT NUMBER: 48
X COORDINATE: 1579102
Y COORDINATE: 335752
GROUND ELEVATION: 11.
WELL DEPTH: 392.

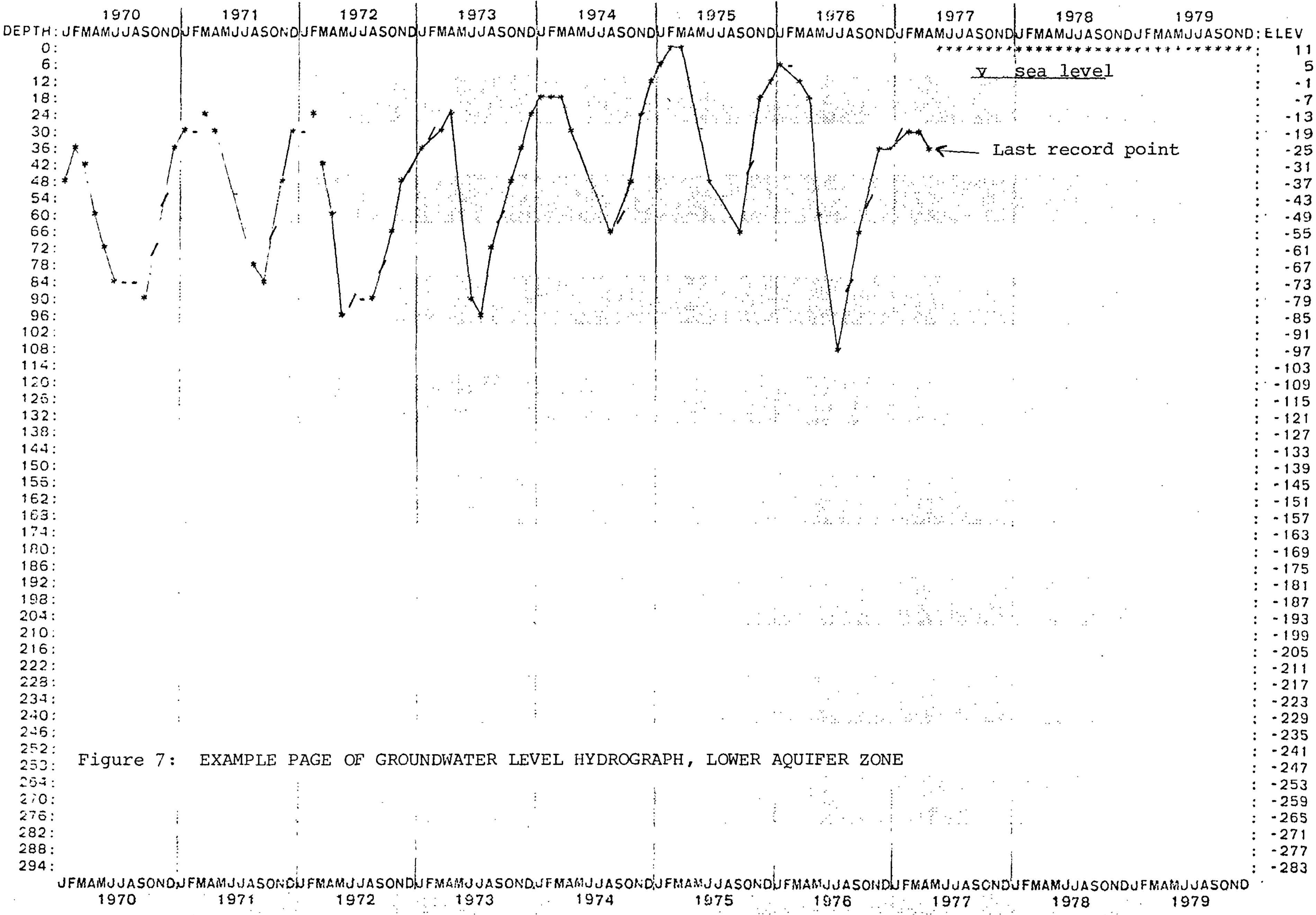


Figure 7: EXAMPLE PAGE OF GROUNDWATER LEVEL HYDROGRAPH, LOWER AQUIFER ZONE

Figure 7

Construction of Monitoring Wells

Thirty additional monitoring wells were constructed at 20 locations in the baylands as part of this investigation. At several of the locations two wells were constructed at a particular site, each to monitor a different aquifer within the upper aquifer zone. The deepest of these wells was drilled to a depth of 102 feet. Most were drilled during the spring of 1977 and the rest during the summer of 1978 under field supervision of the consuting firm, Belogar, Long and Associates. The locations of these monitoring wells are also shown on Plate 6 and a tabulation of well construction data is presented as Table 5. Six exploration test holes were drilled to a maximum depth of 100 feet. At these locations, no significant aquifer was encountered within the upper 100 feet and, consequently, these were not utilized as monitoring wells.

The purposes of constructing these supplementary monitoring wells and exploratory holes were to obtain geologic, groundwater level and groundwater quality data where data points were lacking and to obtain specific data for a particular aquifer for purposes of qualifying and correlating previously obtained data. As it can be noted on Table 3, perforated intervals on all of the current monitoring wells are not available. Some of these wells may be perforated in both the upper and lower zone aquifers and the water level and quality data obtained from them may reflect a composite, or mixed, sample which would not be a true reflection of conditions in either the upper aquifer zone or the lower aquifer zone. One method of distinguishing such compositely perforated wells is through correlation with known conditions of the newly constructed water wells or other wells of know construction.

Other methods used to qualify wells were to correlate water level responses on seasonal and long-term bases with wells of known construction and to correlate chloride and total salt content over a period of time with analyses of samples from known conditions.

TABLE 5

WELL CONSTRUCTION DATA OF NEWLY CONSTRUCTED SALINITY MONITORING WELLS

Well Number	Other No.	Ground Elev. (in ft., approx.)	Well Depth (in ft.)	Perforated Interval (depth in ft.)	Period of Record - Cl Anal. First Date	to Last Date
05S01W36Q01	A-1-S	10	73	63-68	4-27-77	Present
06S01E19M11	G-1-D	37	100	95-100	5-18-77	Present
06S01W02N05	B-1-S	5	35	10-15	5-4-77	Present
06S01W10N04	D-1-S	5	37	27-32	5-17-77	Present
06S01W10N05	D-1-D	5	83	73-78	5-17-77	Present
06S01W10R03	C-1-D	6	100	50-60	5-4-77	Present
06S01W12L03	B-2-S	18	40	35-40	4-27-77	Present
06S01W14L07	C-2-S	13	47	37-42	5-5-77	Present
06S01W14L08	C-2-D	13	94	83-88	5-5-77	Present
06S01W15R02	D-2-D	20	60	41-46	5-17-77	Present
06S01W18D02	I-1-D	5	60	37-45	5-18-77	Present
06S01W20L03	H-3-S	30	31	23-28	5-18-77	Present
06S01W22K06	E-2-D	20	100	60-65	5-10-77	Present
06S01W23K04	D-3-D	28	92	60-65	5-10-77	Present
06S01W24P04	C-3-D	25	96	81-86	5-10-77	Present

TABLE 5 (continued)

WELL CONSTRUCTION DATA OF NEWLY CONSTRUCTED SALINITY MONITORING WELLS

Well Number	Other No.	Ground Elev. (in ft., approx.)	Well Depth (in ft.)	Perforated Interval (depth in ft.)	Period of Record - Cl Anal.	
					First Date to	Last Date
06S01W26K01	D-4-D	27	65	55-60	5-11-77	Present
06S01W26K02	D-4-S	27	26	21-26	No Flow	
06S01W26N03	E-3-S	35	57	48-53	5-11-77	Present
06S01W26N04	E-3-D	35	100	77-82	5-11-77	Present
06S01W36A03	C-4-D	42	55	29-34	5-5-77	Present
06S02W07B12	L-1	13	45	28-45	7-18-78	Present
06S02W10N06	J-1	11	65	50-62	7-18-78	Present
06S02W24J02	I-3-S	30	55	30-50	7-18-78	Present
06S02W24J03	I-3-D	30	104	93-99	7-13-78	Present
06S03W01B04	M-1-D	17	101	93-97	7-11-78	Present

NOTE: Refer to Plate 6 for location of wells.

Review of Sampling Procedure

Wells on the existing salinity monitoring program include privately owned domestic and agricultural wells, all of which are still active. Sampling is conducted by a District water resources technician. When sampling a domestic well, the technician obtains the sample from the tap. In sampling an agricultural well, the technician has authority to turn on the pump. If the pump has been recently operated (technician asks the farmer), the technician would obtain the sample after a short period of pumping. If the pump had not been recently operated, the technician would pump the well a minimum of five minutes before obtaining the sample as to be assured of sampling water pumped out of the aquifer rather than water stagnated in the well.

The newly constructed salinity monitoring wells are small diameter wells with plastic casing installed. These are pumped with a devised airlift system. Again the sample is taken after the well has been pumped long enough to assure that the sample is obtained from the aquifer.

In general, the sampling procedure appears to be adequate. This is largely substantiated by the repeatability of the laboratory analyses results. However, to provide for a greater assurance of a suitable, truly representative sample, the performance of several simple, essentially non-time-consuming tests might be advisable. These are discussed under "Recommendations".

Analyses of Data

After the data were qualified and sampling procedures reviewed, the water level and quality data obtained from these were classified as to represent data from either the upper aquifer zone or lower aquifer zone and, in some instances, the semiperched zone of the upper aquifer zone. The classification of data is a particularly important consideration as to establish the groundwater conditions, not only areally, but also vertically within the basin. Isochlor lines were then plotted for each of the two principal aquifer zones to denote the areal severity of the intrusion.

In order to determine the status of the intrusion, that is, to determine whether a long-term flow or ebb condition is occurring, chloride data, based on repetitive sampling of a particular well over a long period, were graphically plotted against time (a time/chloride-content relationship plot) on as many wells as had sufficient repetitive data. Superimposed on some of the lower aquifer zone plots were hydrograph plots of water levels where water level data were also available for the well or where levels were available in nearby areas representing the depth zone of the sampling data. It has been established that artesian pressure lowering increases the potential for intrusion and the nature of correlation may also give clues to determine the mechanism of intrusion. Through such correlation, a basin operation criterion may be established to minimize future intrusion and/or to conceive projects to prevent intrusion or to reclaim intruded aquifers.

Comparison of isochlor maps may not be definitive enough to determine the status of intrusion, except on a very broad scale, because isochlor maps were not drawn on a regular basis and the data used in the past may not be similary distributed or the interpretation of data may not be the same among the various investigators.

The mixed waters, or transition zone waters, were then characterized. This not only can serve as a basis for characterizing and predicting the mixed quality, but may also provide clues to the interpretive mechanism of the intrusion.

As based upon the review and interpretation of data, conclusions, perspective on future conditions and recommendations are set forth.

CHAPTER IV.

FINDINGS OF THE STUDY

Present Area of Intrusion

In determining the present area and condition of saltwater intrusion in the upper and lower aquifer zones, data obtained from 1972 to 1978 were used. Where numerous repetitive values were available from a particular data point, the prevailing value was used. During this interim period no significant change was noted.

Upper Aquifer Zone

Plate 7 presents an isochlor map of the present condition of intrusion in the upper aquifer zone. The area of definite intrusion is encompassed by the 100 mg/l isochlor line. A 50 mg/l isochlor line is also shown to denote "drop-off" of chloride content values where detailed information was available.

Plate 7 shows the 5,000 mg/l isochlor line fringing the tidelands area or the maximum inland extent of the old historic marshlands area, now largely covered by solar salt evaporator ponds. In the Palo Alto area this isochlor line swings inland of Bayshore Freeway. The 5,000 mg/l line represent essentially the inland extent of the classical case of intrusion. This is preceded by a large but variable transition zone of mixed waters of much lower salt concentrations.

Although the area of intrusion of the upper aquifer zone is one large area fronting San Francisco Bay, certain areas display greater amount of inland intrusion than others. The greater amounts of intrusion occur in areas where aquifers occur more frequently in the subsurface section and where groundwater is more heavily pumped. The area of greatest intrusion is the area south of Alviso along the Guadalupe River and Coyote Creek. Flanking this area to the east and west, fewer aquifers occur. There the land surface of the basin also begins to rise, promoting a seaward hydraulic gradient in the upper zone.

As noted on Plate 4, intrusion of the transition zone around 1940 was greatest in the Palo Alto area as large scale groundwater development was occurring there in the early days of basin development.

As part of the Palo Alto bayfront hydraulic barrier project studies conducted by the District, an anomalous, local area of excessively salty water was delineated. On Plate 7 this area is delineated by the 20,000 mg/l isochlor line. As also noted on Plate 7, the occurrence of this salty body in the upper aquifer zone is located inland from the present Palo Alto bayfront. This bayfront area contains a great complexity of thin aquifers. Of the two principal shallow aquifers in this area, the 20-foot aquifer and the 45-foot aquifer, the lower one has the higher concentrations. Within the barrier project area and as based on 47 data points in the 20-foot aquifer zone, the chloride content ranged from 1,547 mg/l (Well I 1) to 28,300 mg/l (Well S4) and total dissolved solids from 4,352 mg/l (Well I 1) to 57,512 mg/l (Well M3). As based upon 44 data points in the 45-foot aquifer, chloride content ranged from 1,660 mg/l (Well E 1) to 43,520 mg/l (Well E 4) and the total dissolved solids from 4,530 mg/l (Well E 1) to 85,000 mg/l (Well E 4) (Stanford University, May 30, 1977). As noted in Chapter II under "Water Quality", waters of the Bay south of Dumbarton Bridge may vary in chloride content between 10,000 and 17,000 mg/l and contain about 35,000 mg/l total dissolved salts. A number of the analyses of samples from both the 20-and 45-foot aquifer revealed salt concentrations to be higher than Bay Water, indicating that the upper aquifer zone water at this location had undergone some process to concentrate the mineral salts.

No data are being collected for the quality of water in the upper zone beneath the saltwater marshes, solar evaporator ponds and southern San Francisco Bay. Previous data developed by the California State Department of Water Resources in their studies of the saltwater intrusion in the Niles Cone area in Alameda County (December 1960, August 1968) indicates the Newark aquifer which occurs in this upper zone is highly intruded.

Groundwater quality within the semiperched zone is not monitored except at only a few locations near the edges of the saltwater marshlands. The limited samples from this zone indicate chloride content to be about 5,000 mg/l. Degraded quality waters can be expected in this zone due to poor drainage conditions and from accumulations of agricultural waste water, as discussed in Chapter II under "Water Quality" and "Soils". The degraded waters in this zone may not necessarily be attributed to saltwater intrusion. Saltwater intrusion in this semiperched zone may be occurring only in areas in contact with saltwater bodies such as at the bayfront, and at locations adjacent to the solar salt evaporator ponds or along stream channels where tidal incursion of saltwater occurs.

As noted previously, tidal incursion up Guadalupe River is up to Montague Expressway but the incursion up Coyote Creek is blocked at Standish Dam, located near the old Milpitas sewage treatment plant. This temporary flashboard dam is normally operated from spring to fall to create a freshwater pumping sump for diversion of surface water by local irrigators. It is suspected that the operation of this structure has a large influence in limiting the saltwater intrusion in the Coyote Creek area.

Lower Aquifer Zone

Using data from wells deeper than 150 feet, an isochlor map of the lower aquifer zone was constructed and is presented as Plate 8. Also presented on the map are the locations of the lower aquifer zone wells on the present monitoring program. In addition three deep wells constructed for the District saltwater intrusion hydraulic barrier project and six City of Palo Alto municipal wells are shown on the map; these latter wells were added to show the degree of control in outlining areas of intrusion in that area.

As shown on the isochlor map three known areas of intrusion are noted. The three areas outlined, or partially outlined, are 1) along Guadalupe River south of Alviso where the overlying upper aquifer zone is intruded, 2) Palo Alto bayfront area where also the overlying upper aquifer zone is intruded, and 3) Palo Alto area west of Highway 101 where the upper aquifer is not intruded. It is doubtful that the intrusion in the two lower zone areas in Palo Alto are directly connected as datum from an intervening well between the two areas, Well I1 (05S02W31K13) a deep zone monitoring well for the hydraulic barrier project, does not indicate a condition of saltwater intrusion.

As also shown by the isochlor map of the lower aquifer zone, the three known areas of intrusion are only mildly intruded. In most recent years the chloride content have been mostly less than 300 mg/l.

Recently (April 1977) during drilling of a water well near the intersection of Highway 17 and Dixon Road northwest of Milpitas, the driller noted salty water in the shallow aquifer zone and suspected that the upper portion of the lower aquifer zone may have been mildly intruded. As the lower zone could not be isolated from the upper zone during drilling and sampling, the intrusion condition of the lower zone at that location could not be confirmed.

In times prior to 1972, the intrusion within the lower aquifer zone may have been more severe and may have encompassed a larger area. In the 1960's several areas within the zone were known to be intruded but the most recently obtained data in these areas show no or little contamination. These include 1) the area of the City of Palo Alto's Hale well (05S03W35G10), 2) the area near the intersection of San Antonio Road and Highway 101 (noted in City of Los Altos' sewage treatment plant well and Casey's Palo Alto Ready-mix well) and 3) possibly at Moffet Field U. S. Naval Air Station. The City of Los Altos and Casey's Palo Alto Ready-mix wells have been sealed.

Status of Intrusion

The following discussion relates to whether the saltwater intruded areas are enlarging inland and whether the severity of intrusion is increasing or becoming smaller and are conditions improving? These were determined by graphically plotting repetitive chloride data against time for particular wells where sufficient records are available and by comparing present condition isochlor maps with historic isochlor maps (as discussed previously in Chapter III under "Analyses of Data").

Upper Aquifer Zone

Repetitive chloride content data from a particular well on a long-term basis were available for only a few wells in the upper aquifer zone. All of these are located in the mixed transition zone in the Guadalupe River area south of Alviso. Plate 9 exhibits two examples of time/chloride-content plots for respective particular wells. Data from well 06S01W15G01, a 60-foot deep well located adjacent to the Guadalupe River one and one-half miles upstream of Alviso, spans a time period from 1961 to the present with a data gap from 1971 through 1973. As shown on the graphical plot, the chloride content in the well ranged widely from about 210 to 700 mg/l during the period from summer of 1961 to fall of 1970. Then from the spring of 1974 the chloride content dropped with a much narrower range of fluctuation, from 135 to 255 mg/l. Interestingly, during the period from 1961 to 1970, the wide range of fluctuation appears to be cyclic following the seasons with most of the annual peak chloride levels occurring during the fall and lows during the spring, indicating the highest seasonal chloride content to occur toward the end of the pumping season. Long-term water levels over a similar period within the upper aquifer zone in the nearby area is not available and, hence, such a correlation could not be made. The wide range of seasonal chloride content fluctuation indicates a nearby source of intrusion, perhaps drawing in saltwater during pumping from saltwater that incurred up the Guadalupe River from the Bay. In checking the pumping history of this well, it was determined that the well was pumped much more intensively during the 1960's than at present, thus accounting for the higher and more variable chloride content during that period. After 1974 ,when chloride content was lower, static water level in this well was just above sea level with hardly any fluctuation, based on eleven interim readings.

Well 06S01W14P02, a well suspected to be less than 100 feet deep, is located farther upstream than well -15G01, approximately two and one-half miles south of Alviso and about one-quarter mile east of the channel of the Guadalupe River. The period of chloride content data availability is from summer of 1961 to fall of 1970. Located farther upstream than well-15G01, the chloride content is lower and ranged from 100 mg/l to 263 mg/l. As it can be noted on the time/chloride-content plot on Plate 9, a similar cyclic variability upon a seasonal basis occurs, with most of the peak chloride occurring in the fall, but with the degree of variability in a much smaller range. It is suspected that the smaller range of variability is due to the overall lower chloride content and the greater distance of the well from the source of the intrusion, that is Guadalupe River.

Longer-term chloride content data, but on an erratic frequency, are available for well 06S01W14L04 which is located within a quarter of a mile of well 06S01W14P02 on First Street, one-half mile away from the channel of the Guadalupe River. This well is 90-feet deep. Chloride content data available for this well consist of two measurements in the summer of 1949, annual measurements from 1952 to 1957 (different times of the year) and 1959 to 1960, and on a regular every-other-month measurement basis from 1974 to the present. These measurements (not presented in this report), indicate chloride content to be about 110 mg/l during the summer of 1949, dropping below 50 mg/l during 1952 to 1956, rising to 140 mg/l in 1957, and dropping to about 15 to 20 mg/l in 1959 and 1960. During the years of higher frequency of measurements, from 1974 to the present, the chloride content held rather steady at around 80 mg/l with a few erratic points ranging from 15 to 125 mg/l. Data for this well was lacking from 1961 to 1974 during which period other wells in the area indicated chloride content well over 100 mg/l. Static water levels of this well are available from 1970 to the present. Levels during this period held rather steady and above sea level with occasional points dropping to about sea level.

In summary, data from samples south of Alviso indicate that the status of intrusion had improved, or receded, since the peak occurrences in the 1960's, but in more recent years (1974 to the present), it has been holding steady.

In the Palo Alto area, only a few short-term repetitive data for wells are available (existing monitoring wells are located southwest of the highly concentrated saltwaters entrapped in the upper bayfront aquifers). These are from 1974 to the present. These plots either show no definite trend or the suggested subtle trend shown would require a much longer period of data for confirmation. Of those available, the chloride content averages about 100 mg/l or less. In some instances wide ranges of erratic chloride content were noted during short-time intervals.

Broad generalizations can be speculated by comparing previous saltwater intrusion maps to the one prepared for this report as Plate 7. Since 1940, when Tolman and Poland prepared their map, intrusion has become greater in comparing it to the isochlor map prepared by Inerfield and Ellis (September 1975) which shows the maximum extent of intrusion at one time or another. It is suspected that the maximum extent of intrusion may have occurred in the 1960's. In comparing the rough approximation of the areal extent of the classical case intrusion front (5,000 mg/l chloride content line) of that inferred by Inerfield and Ellis (Plate 5) to that prepared for this study, it can be speculated that this front, though ill defined, has changed very little. However, the mixed transition zone as indicated on the isochlor map prepared for this study encompasses a smaller area than that shown by Inerfield and Ellis, suggesting that the present area and severity of the transition aureole has diminished since the 1960's. The conditions of intrusion in the most recent years, since about 1970, appear to be static.

The condition of intrusion has diminished since the 1960's because groundwater pumping from the upper aquifer zone had been reduced since then. This has resulted from services being replaced by imported Hetch-Hetchy service or by pumping of unintruded groundwaters of the lower aquifer zone. This has allowed water levels in the upper zone to recover.

No long-term chloride data are available for the semiperched zone. In areas in contact with Bay waters, it is speculated that a condition of equilibrium has been established, minimally disturbed only by tidal fluctuations.

Lower Aquifer Zone

As previously discussed and shown on Plate 8, the degree of degradation due to saltwater intrusion in the confined lower aquifer zone is very mild and the area of intrusion encompasses relatively small areas. Several long-term repetitive chloride content data from particular wells are available for the area south of Alviso; long-term piezometric levels are also available in this area. The data availability in the Palo Alto area is meager and erratic or virtually nonexistent.

Plate 10 shows two examples of time/chloride-content plots for the area south of Alviso. During the 1960's, water in both wells showed saltwater contamination. Chloride data for well 06S01W23C01, which is located three miles south of Alviso and adjacent to Guadalupe River, consists of an isolated data point in 1961 and a regular series of points from the spring of 1964 to the summer of 1970. This well is 728-feet deep. The graphical plot indicates a condition of intrusion from 1961 to the fall of 1966, with peak chlorides of just above 250 mg/l. The seasonal variability, though rather small, can be noted, indicating that intrusion was most severe at end of the pumping season. Then from the fall of 1966 to the summer of 1970 the chloride content decreased rather dramatically to generally below 50 mg/l. In comparing the time/chloride-content plot to the piezometric level plot of a nearby well, 06S01W23K01, the prevailing high chloride content period was during the long-term peizometric low period and then the chloride content decreased all of a sudden as the piezometric level began a long-term rise. Well -23K01 is 270-feet deep.

Chloride content data for well 06S01W15H01, located one and one-half miles south of Alviso along First Street, is available from 1959 to the present with a gap from the summer of 1970 to the spring of 1974. This well is 392-feet deep. The chloride data indicate mild intrusion occurring seasonally from 1965 through 1968. During the years when the high peaks occurred, piezometric levels in this well were at their lows, but with a slight time lag as the peak chloride content of 160 mg/l occurred in the summer of 1967 after the long-term piezometric levels began to rise after the summer of 1965. Time lags involving chloride highs and piezometric level lows can be expected when the source point of the contamination from the upper to the lower aquifer zone is not in the immediate area of the sample point. The interesting aspect of the plots of the lower aquifer zone is the relatively rapid long-term increase and decrease in chloride content with time. The implication is that during the long-term lows in piezometric levels, slugs of contaminated water are drawn into the lower aquifer during seasonal pumping periods and this flow ceases or decreases to extremely low volumes when the pumps are idle and the cones of depressions formed during pumping are recovering.

Other time/chloride-content plots for lower zone aquifers in the nearby areas of the two previously discussed wells indicate similar conditions, showing peak chloride contents in the mid to late 1960's and then decreasing to lower levels in the 1970's.

In the presently intruded area within a mile south of Alviso, similar rapid buildup and decline of chloride content with time was noted, but the degree of seasonal variations was much larger than in the outer fringe areas. The time/chloride-content plot for well 06S01W16A01, which is suspected to be a deep zone well and is located one mile southwest of Alviso, shows chloride levels below 20 mg/l from 1949 to 1957 (plot not presented in this report). Then a gradual increase to about 180 mg/l was noted in the fall of 1960. From the fall of 1960 to the summer of 1968, the chloride content dramatically increased to an erratic peak level of 1,080 mg/l in the summer of 1963 before starting to decline. Wide seasonal variations in chloride content were noted during the generally high chloride content period. From the summer of 1968 to the fall of 1970 (end of data availability for this well), the chloride content leveled off to between 100 to 200 mg/l. The high chloride content period between 1960 and 1968 was coincident with the long-term lower aquifer zone piezometric low period.

At present, the chloride content in the lower aquifer zone just south of Alviso ranges from about 100 mg/l to less than 300 mg/l, indicating considerable improvement since the mid and later 1960's; but in most years from 1974 to the present, the status of intrusion appears to be static. The wide seasonal variations of chloride content during the period of worst intrusion add to the confirmation of the conclusion that seasonal slugs of contaminated water are being drawn into the aquifers, principally during periods of pumping drawdown during those years of historic piezometric level lows.

When comparing the lower aquifer zone time/chloride-content graphical plots with those of the upper zones, a difference can be noted. In general, the increase and decrease in the long-term chloride content changed more abruptly in the lower aquifer zone, these being related to the long-term piezometric cycle changes. Another difference is that the prevailing chloride content in the upper zone is generally higher while the lower zone exhibits sharper individual peaks. Several of the time/chloride-content plots exhibit a hybrid-type plot of the two zones. These may be a reflection of the well being compositely perforated in both the upper and lower aquifer zones.

Long-term repetitive data from particular wells in the Palo Alto bayfront area are not available. For the inland area of intrusion in Palo Alto, a crude time/chloride-content plot was constructed, based on the scattered data points for the City of Palo Alto's Hale well, 05S03W35G10, located adjacent to San Francisquito Creek. Another crude time/chloride-content plot was constructed for the Rinconada Park area off Embarcadero Road, based on scattered data points from several nearby City of Palo Alto wells. These graphical plots are presented as Plate 11. Many of the wells along Palo Alto bayfront perforated in the lower aquifer zone, such as the Ravenswood well and those in San Francisco Bay, have long been destroyed, either intentionally or through disrepair.

The Hale well is located just north of the currently intruded area but in previous times had indicated chloride content above 100 mg/l. This well is 934-feet deep and is known to be preforated at various intervals from a depth of 102 to 840 feet. The scattered data points span a period from spring, 1949 to summer, 1961 and from the summer of 1972 to the fall of 1975. The available data indicated chloride content above 100 mg/l during the summer and fall of 1949 and then dipping below 100 mg/l through the summer of 1955. From the spring of 1956 to the summer of 1961, the chloride content averaged about 190 mg/l with a peak reading of 215 mg/l during the fall of 1958. Following the period of data gap, a single reading of 309 mg/l was recorded during the summer of 1972. Two subsequent readings in 1974 and one in 1975 indicated the chloride content to be below 100 mg/l. This well was pumped until 1962 when the City of Palo Alto switched to Hetch Hetchy water service. Since 1962 to the present (period of water level data availability) the piezometric levels in this well steadily rose, recovering from a depth of about 180 feet to 40 feet (about 13 feet above sea level) in 1977.

The local area of intrusion of the lower aquifer zone in the Rinconada Park area inland from the Palo Alto bayfront is one of mild intrusion. In 1949, wells 06S03W01D01, 06S03W01M01, both suspected to be tapping water from the lower aquifer zone, and 06S03W01B01, 446 feet deep, indicated chloride content to be below 100 mg/1. Well 06S03W01B01 showed chloride content rising to about 100 mg/1 in 1951, 1952, and 1953 as based on single data points for each year. A nearby well, 06S03W01B02, indicated a steady rise in chloride content from 1954 through 1961, rising from about 190 mg/1 to 218 mg/1. This well is 1,082 feet deep and is perforated at various intervals from a depth of 150 to 1,082 feet. Isolated data points from a deep well (depth unknown) at Rinconada Park, well 06S03W01C12, indicated chloride content to be 204 mg/1 during the winter of 1961, 280 mg/1 during the fall of 1972, 90 mg/1 during the spring of 1974, 221 mg/1 during the fall of 1974 and finally 135 mg/1 during the fall of 1975. This well, as have other existing City of Palo Alto wells, has gone on standby service since the City switched to water service from Hetch Hetchy in 1962. The chloride content in the upper aquifer zones at Rinconada Park was determined to be less than 50 mg/1 as indicated in a

25-foot-deep well, 06S03W01C11, during the period of record from the winter of 1974 to the present. The bottom of this well is about one foot below sea level. The recently drilled monitoring well, 06S03W01B04 (M1), located adjacent to Rinconada Park, indicated a chloride content from 22 to 25 mg/1 during the period from September 1978 to March 1979. The ground elevation at this well is about 13 feet, and its perforated depth interval is from 93 to 99 feet, thus tapping upper aquifer zone water from a depth below sea level. With the upper zone groundwater at the Rinconada Park area virtually unintruded, the intruding saltwater had to migrate to this area within the lower zone aquifers from points beneath the upper aquifer zone nearer the Bay.

From 1974 to the present, chloride content in wells 06S03W01D10 and 06S03W01M10 indicate chloride content generally below 50 mg/1. It is not known whether the areas of these two wells lying just outside the Rinconada Park area were ever intruded. Isolated earlier data points in 1949 had indicated a condition of intrusion.

Another area noted where intrusion into the lower zone has occurred is a local area near the intersection of Highway 101 and San Antonio Road. A 300-foot deep well perforated at depths between 167 and 175 feet was completed on September 15, 1956, at the Los Altos Sewage Treatment Plant, located at the northern end of San Antonio Road near the southern edge of the solar salt evaporator ponds. Chloride content was reported to be 30 mg/1 (letter from Brown and Caldwell, Inc. to City of Los Altos, April 21, 1958, although in an earlier letter dated September 17, 1956, chloride content was noted to be 253 mg/1). On February 25, 1958, after two weeks of continuous pumping of this well, a sample analysis indicated chloride content to be about 3,000 mg/l. A seal was placed to prevent near-surface water from entering the well but this did not improve the quality of the discharge. A test well was started on March 31, 1958, adjacent to the well to seek suitable aquifer beneath a depth of 300 feet. One was found below a depth of 790 feet and the hole was continued to a depth of 910 feet where some gas and oil were encountered in the formation. Electrical resistivity logging of the test hole was conducted which indicated greater salinity at the lower depths. This test hole was backfilled with concrete. In March of 1958, a well for Casey's Palo Alto Readi-mix was drilled 800 feet east of the sewage treatment plant well. This well was originally perforated in the 167-175-foot gravel zone but after hearing the plight of the sewage treatment well, the perforations were sealed and the well as constructed deeper to tap water from below 300 feet (still during the spring of 1958). The deeper aquifer water was reported to be an excellent quality water till at least June, 1961 (time of last reporting).

In the same vicinity as the Los Altos sewage treatment plant well, monitoring well 06S02W05Q03(D2) was drilled for the Santa Clara Valley Water District saltwater intrusion hydraulic barrier project in November, 1976. This well is located 700 feet west of the sewage treatment plant well and was drilled to a total depth of 200 feet, perforated at depths between 178 and 183 feet. Analyses of samples from this well in July and September, 1978 indicated chloride content to be 17 and 18 mg/l, respectively. These last analyses indicate that the lower aquifer zone intrusion condition had significantly improved and is considered no longer intruded.

In summary, the status of intrusion in the lower aquifer zone in the area south of Alviso has improved since the piezometric levels reached their lows in the 1960's. Most recent conditions, from 1970 to the present, appear to be rather steady and unchanging. In the Palo Alto area certain areas of intrusion also have shown improvement after the Cities of Palo Alto and Mountain View switched to water service from the Hetch Hetchy system which resulted in rising piezometric levels of the lower aquifer zone. However, the status of mild intrusion in the lower aquifer zone in the Rinconada Park area in Palo Alto and the Palo Alto bayfront area is uncertain, despite the rise in piezometric levels from their historic lows. The deep well at Rinconada Park continues to indicate an apparently isolated body of intruded water in the lower zone as other deep wells in the area indicated an absence of intruded conditions, including deep wells located between

Rinconada Park and the bayfront. Groundwater in the upper aquifer zone above the deep pumping zone at Rinconada Park at present indicate unintruded conditions although this zone may have been intruded in the past. More repetitive data are required for these areas in order to determine the status of intrusion.

Since no previous isochlor map of the lower aquifer zone is available, the status of intrusion could not be compared and determined in this manner.

Geochemical Aspects of Intrusion

The geochemical aspects of this study were to identify the character of the mixed transitional water in the aquifers of native freshwater and intruding salty water and to identify, if possible, some of the geochemical processes involved. As it will be pointed out, the result of the mixing will not be easily predictable because of the mineralogical diversity of native freshwater and the geochemical processes that occur with the formation materials.

As discussed previously, uncontaminated native groundwater in the upper and lower aquifer is a variable cation bicarbonate type of good quality and the intruding seawater and concentrated saltwater are a sodium chloride type. Semiperched groundwater uncontaminated by seawater is usually already degraded water of variable mixed cation and anion types affected by agricultural wastewater and concentration process due to poor drainage. The most obvious and predictable results of saltwater intrusion in the mixed water, especially when intrusion is severe, are higher total mineral salts and higher sodium and chloride, although the expected proportion of reacting values of the constituents may not result as if it were a simple mixture.

In order to assess the more subtle changes that might occur in the mixed transition zone and to identify any geochemical processes that might result, a graphical trilinear plotting of reacting values of the major cations and anions as based on equivalent weights was attempted. On the graphical plots, the mineral character of uncontaminated water, Bay water, and mixed waters were plotted. Where complete mineral analyses were available, trilinear plots were attempted for wells progressing inland from the Bay through the mixed zone to uncontaminated areas and also vertically from the intruded upper aquifer zone to the slightly intruded lower aquifer zone. If the mixing of freshwater and seawater results in a predictable point between the mixing waters, no or little geochemical process was assumed.

Water quality changes as a result of intrusion in both the upper and lower aquifers in the area south of Alviso are shown on trilinear plots presented as Plates 12, 13 and 14.

Plate 12 shows upper aquifer zone data points along Line D which starts from the Southbay estuary at Alviso southward along Guadalupe River through the mixed transition zone to Brokaw Road where the upper aquifer is not intruded. The correlativeness of the data points as related to respective aquifers can also be inferred on the accompanying geologic structure section. A sample (spring, 1977) from well 06S01W36A03(C4D) located near Brokaw Road indicated the water to be an unintruded calcium-magnesium bicarbonate type with a TDS of 618 mg/l and a chloride content of 38 mg/l. This is a similar type to water samples taken from the Guadalupe River far upstream on February 8, 1949 but with a higher dissolved salts content. The succession of wells along Line D toward the Bay shows an increasingly aggravated condition of intrusion, as noted in wells 06S01W26K01(D4D), 06S02W23K04(D3D), 06S01W15R02(D2D) and finally 06S01W10N04(D1S), the last showing sodium chloride type water similar in mineral character to Bay water, with a TDS of 12,140 mg/l and chlorides of 7,250 mg/l in the spring of 1977. As can be noted on the trilinear plot, the reacting values of sulfate are proportionately higher than expected among the anions, and the cations showed expected higher sodium values as a result of the intrusion and mixing. The higher sulfate value cannot be the result of simply mixing freshwater with seawater as based upon the indicated anaylses. The increase could result from an applied source or through geochemical processes. Hem, 1970, indicated that the solubility of gypsum (hydrous calcium sulfate) may increase in the presence of increasing sodium chloride solution concentration. Gypsum and sulfuric acid are, or have been used by some farmers in the baylands areas as soil amendment to improve drainage and alkaline soil conditions and may represent the source of the additional sulfates.

Well 06S01W10N05, constructed in the same hole as well -10N04 but perforated in a deeper aquifer, is only mildly intruded and shows no anomalous pickup of sulfate as was noted in the higher aquifer. This is accountable by either soil amendments were not used in the area or that applied soil amendments only have a significant influence in the uppermost aquifers.

In wells located in the mixed transition zone along First Street south of Alviso, a similar rise in reacting values of sulfate among the anions was noted and also a slight rise in magnesium and sodium among the cations as shown on the trilinear plot on Plate 13. Also shown are the changes in mineral type of water from well 06S01W14L04, 90-feet deep, which showed that the aquifer perforated at that location was unintruded in August 1954, intruded in August of 1957, and the intrusion flushed by freshwater in August 1960. Similar changes occurred as a result of the intrusion and the water nearly reverted back to its original freshwater mineral character after flushing.

In considering the changes that occur in the lower aquifer zone as a result of intrusion in the area south of Alviso, the mineral characteristics of Bay water, the intruded mixed groundwater in the overlying upper aquifer zone and mixed waters of the lower aquifer zone were plotted. This was done in an attempt to analyze the progression of changes that might be tied to the mechanism of intrusion into the lower aquifer zone from the upper zone. This attempt is indicated, in part, on Plate 12 by points A (Bay water), B and C (two aquifers levels of the upper aquifer zone) and on Plate 14 that shows the resulting trilinear plot of samples from wells completed in the lower aquifer zone. On Plate 14, data from wells 06S01W14E01 and 06S01W16A01 indicated groundwater conditions when unintruded or flushed by freshwater and when intruded. Data indicated a predictable simple admixture among the anions but some deviations among the cations.

Well 06S01W14E01 which was intruded and then flushed showed hardly any changes in reacting values among the cations when the aquifer was flushed while the chloride content was predictably reduced. In August 1966, the mildly intruded water was a calcium-sodium bicarbonate type with a TDS of 536 mg/l and a chloride content of 138 mg/l. Upon flushing in August 1972, the water changed to a mixed bicarbonate type with a TDS of 412 mg/l and a chloride content of 40 mg/l.

Samples from well 06S01W16A01 indicated an unintruded condition in August 1954 and then an increasing severity of intrusion in samples of August 1960, September 1961, and August 1963. Samples of August 1966 and October 1970 indicated a flushing trend of the aquifer by freshwater. As it can be noted on Plate 14, the original unintruded groundwater was a sodium bicarbonate type with a total dissolved solids content of 284 mg/l and a chloride content of 14 mg/l. With the progression of the severity of intrusion, a normal increase in chloride content was noted rising to a peak concentration of 1080 mg/l while the proportion of reacting value of the cation showed abnormal trends. It would be expected that proportionate reacting values of sodium would increase as to approach that of Bay water. However, at the peak concentration of 2,450 mg/l TDS, the proportion of reacting values of calcium and magnesium increased at the expense of sodium and the water was then a mixed cation chloride type. This apparently abnormal change of the reacting values of the cation can be explained by the nature of the intrusion having occurred from the mixed transition zone water of the upper aquifer zone. Base exchange in the lower aquifer zone within the baylands area has changed the native waters from a calcium-magnesium bicarbonate type as it occurs in the forebay and mid-fan area to a sodium bicarbonate type. Groundwaters of the upper aquifer zone had not experienced as much base exchanged and the mixed transition groundwater is largely a mixed cation type water and, hence, the resulting mixed chloride type water can be expected when intrusion is relatively mild. Undoubtedly, if the intrusion had become much more severe, a normal change would be expected approaching the character of Bay water. Then, as the flushing of the aquifer started and progressed, the quality started to revert back to its original unintruded quality, but as the flushing at the last data point was still incomplete (TDS of 500 mg/l), a residual chloride content still remained at 202 mg/l. The change in pH with the intrusion and flushing showed a regular trend starting at 8.4 when unintruded and lowering to 7.7 at the most severe intrusion noted in this well and then reverting back to 8.3. However, such regular changes of the pH with advancing and regressing intrusion appeared to the exception when compared to the vast majority of other data.

In the Palo Alto outer fringe area of intrusion within the upper aquifer zone, where the intrusion is mild, the trilinear plots showed rather a normal admixture of the anions (not shown in this report). Only a few showed a slight proportional rise in reacting values of sulfate. The changes of the reacting values of the cations could not be determined as the native unintruded waters showed a diverse proportion of the various cations due to cation exchange from one location to another and comparative data were not available.

Some areas just outside the present fringe area of intrusion southeast of Palo Alto show slightly higher than normal sulfate content in the upper aquifer zone. This area may have been mildly intruded in the past. Gypsum and sulfuric acid soil amendments may have been applied by some farmers in the area.

The mildly intruded lower aquifer zones in the Palo Alto area, in general, showed the same changes as noted in the upper zone of the area. At one data point, well 06S02W07G01, which is suspected to be tapping the lower aquifer zone, more definitive data was obtained. A sample taken in July, 1951 showed the well water to be unintruded and another sample taken in August, 1953 showed it to be mildly intruded. The first sample indicated the water to be a sodium bicarbonate type with a TDS of 375 mg/l and chloride content of 56 mg/l. After being mildly intruded, the well water became a mixed cation bicarbonate type with the TDS rising to 514 mg/l and chloride content to 101 mg/l. The trilinear plot as presented as Plate 15 shows a normal admixture among the anions with expected higher chloride content but, like in the previous example of the lower aquifer zone changes in the Alviso area, a higher proportionate of amount of reacting values of magnesium and calcium among the cations at the expense of sodium was again noted.

The highly concentrated sodium chloride water area near the Palo Alto bayfront area in the upper aquifer zone is being studied by Stanford University (May 30,1977). As shown on Plate 15, the character of the highly concentrated connate water is similar to Bay water but has a much higher total dissolved salts content. In a graduate thesis, T. R. Pinkos (August 1976) noted a rise in some wells of the sulfate content upon intrusion, similar to that noted in the uppermost intruded aquifer south of Alviso. In some other samples he noted lower sulfate content which may indicate conditions for sulfate reduction to occur upon intrusion as indicated in other areas of seawater intrusion (outside the study area). Sulfate reduction process results in lowering of the reacting values of sulfate with a rise in bicarbonate among the anions. He based the possible occurrence of this process on the very high pH (ranging from 10.8 to 12.7) and high alkalinity noted in some of the samples. This author speculates that the anomalously high pH and high alkalinity in some of the samples were the result of insufficient pumping of the wells prior to obtaining samples and the high values represent contamination from the concrete annular seals in these then newly constructed wells.

In summary, the geochemical processes most commonly observed as a result of intrusion are base exchange among the cations and solution enrichment of sulfate among the anions, in the presence of a higher sodium chloride content, the latter process occurred in many areas of the uppermost aquifers and may be attributed to the application of gypsum or sulfuric acid as soil amendments in some farming operatons. In general, other than the rise of total mineral salts, sodium content and chloride content, it was found that normal predications of admixtures resulting from intrusion could not be made, especially when the condition of intrusion was mild. This could be attributed to the following reasons:

(1) Native unintruded waters are of various mineral types and the distribution of the various types of water could not be adequately ascertained to perform meaningful comparisions.

(2) The ratio of freshwater and saltwater in any mixture is difficult to ascertain at any particular time, particularly under dynamic conditions when saltwater might be being drawn into the aquifer by pumping.

(3) Geochemical processes that might be occurring upon mixing may not be easily identifiable.

(4) Correlation of individual aquifers, is difficult due to the geologic complexities.

Thus, at this time, the only criteria arbitrarily used is the 100 mg/l chloride content threshold to indicate saltwater intrusion in the bayfront area in Santa Clara County. Even this has to be tempered with judgment.

Interpretive Mechanism of Intrusion

Upper Aquifer Zone

Under the concept of classical intrusion of an aquifer, movement of saltwater inland is largely by displacement of freshwater in response to inland (reverse) hydraulic gradients. It was determined as based upon data and analyses that this type of intrusion has occurred in the Santa Clara County bayfront area but to a very limited extent, perhaps to just inland of the Bay, estuaries and solar salt evaporator ponds. This is in contrast to the greater inland distance of intrusion that has occurred in the Niles Cone area in Alameda County.

In a large part of the baylands area in Santa Clara County, a large aureole of mixed transition zone waters occur in the shallow aquifer zone inland of the classical intrusion front, much larger than can be accounted for in a classical type intrusion. The question arises as to how to account for the large mixed zone aureole. Two possible explanations are:

1) That the saltwater might be entrapped in the clay layers bounding the aquifers and have not undergone flushing as freshwater originally discharged into the Bay through the leaky aquitard before pumping occurred in the area. In this scenario a mild contamination by saltwater occurs when the aquifer is pumped and the reduced pressures in the aquifer would allow small volumes of connate saltwater to enter the aquifer from the clay beds. This would then not constitute a case of intrusion.

2) Saltwater incurring up the stream from the Bay vertically seeps through a leaky clay cap into the upper aquifer zones in response to pumping drawdown of the aquifer water levels.

The first hypothesis was evaluated by soils sampling of the aquitard materials, either just above or below the aquifer at several locations, and analyzing soil-water extract from the soil samples for mineralogical quality. These analyses indicated the soil-water extracts to contain lesser chloride content than the mixed waters in the aquifer and, hence, this hypothesis was rejected as a possible mechanism.

Based upon the accummulated data and evidence, the second alternative hypothesis appears to be correct. The following discussion covers the basis for the development of this hypothesis.

The areal pattern of intrusion at different times as interpreted on Plates 4, 5, and 7 indicates a relationship of intrusion to the Guadalupe River and Coyote Creek. The farthest inland intrusion occurs along the Guadalupe River which is located along the valley thalweg which is topographically suitable for the greatest amount of upstream incursion of Bay water. This incursion has been aggravated by land subsidence and stream channel modification (deepened and leveed) for flood control protection. These modifications allowed farther inland incursion since the 1920's. Spot sampling of waters along the Guadalupe River indicate the incursion of saltwater progresses upstream to about Montague Expressway, approximately three miles upstream of Alviso. Highest mineral salt content occurs during summer and fall when the incursion is not diluted by natural runoff. The incursion up Coyote Creek was not sampled, but any meaningful incursion would be blocked at Standish Dam near the old Milpitas sewage treatment plant most of the year except during periods of winter and spring runoff.

Correlation of the areal pattern of intrusion with the abundance of aquifers compared to areas of scarcity of aquifers in the upper zone compares very well. Aquifers beneath Guadalupe River and Coyote Creek are abundant while the area between the two streams contain few aquifers and, consequently, intrusion in this intervening area has not progressed inland as far. This also holds true in other areas where aquifers are less frequent in the upper zone.

The next question is how the saltwaters incurring up the streams enter the aquifers beneath the surface under the prevailing geologic and hydrologic conditions. The surface is essentially capped by clayey materials and the individual upper zone aquifers are separated by clayey interbeds. Also, many of the upper zone aquifers are under some degree of confinement as exhibited by static water levels in wells standing above the top of the aquifers. The deeper aquifers in the upper zone are more likely to have a greater degree of confinement than the semiperched and upper aquifers.

The answer lies in that the clay cap at the surface and the intervening clay beds would nevertheless have to be leaky, implying a condition of partial confinement or that the clay cap may be discontinuous or thin enough as to contribute to the leaky condition. The leaky condition and areas of various degrees of leakiness are not expected to be areally uniform. The suspected leakiness of the clay cap and intervening upper zone clays are based upon the following premises:

1) W. O. Clark (1924) presented a map showing the locations of flowing and nonflowing artesian wells within Santa Clara County. Of particular interest on this map is that the flowing and nonflowing wells occur together within the baylands. W. O. Clark determined that the nonflowing artesian wells in the baylands area are shallow wells tapping the upper aquifer zone, implying that the pressures are or have been dissipating

as waters leak upward into the Bay or estuaries. This is in contrast to the flowing artesian wells which tap the deep aquifer zones which are overlain by essentially impermeable clay beds which provide a condition of "perfect confinement". The condition of natural discharging of waters into San Francisco Bay when original hydraulic gradient was toward the Bay has also been cited in California State Water Resources Board Bulletin 7 (June 1955).

2) The few available continuous water level data for wells completed in the upper aquifer zones indicate a rather narrow range of seasonal fluctuation, resembling that of water table conditions rather than a wide range of seasonal fluctuation that is characteristic for wells completed in the confined lower zone aquifers. However, this could also be attributed to the smaller volumes of water pumped from the upper aquifer zone than as from the lower aquifer zone.

3) The controlled aquifer tests performed for the Santa Clara Valley Water District hydraulic saltwater barrier project at Palo Alto indicated a leaky aquifer condition in upper zone aquifers. Pump-out aquifer tests utilizing nearby observation wells of the 20-foot and 45-foot aquifers indicated the clay cap and the intervening clay bed between the 20- and 45-foot aquifers to be leaky.

4) Farmers along Guadalupe River in the baylands area have reported damaged or killed crops on lands adjacent to a channel by severe saltwater incursion up the stream or by slugs of polluted waters discharged into the stream (personal communication). This indicates the occurrence of some degree of communication between water in the stream and adjacent lands and with the semiperched groundwater zone.

5) Salt and alkali accumulations in soils in inland areas unaffected by tides indicate discharging waters into the atmosphere. This accumulation can certainly be aggravated by slowly discharging groundwater in the true sense.

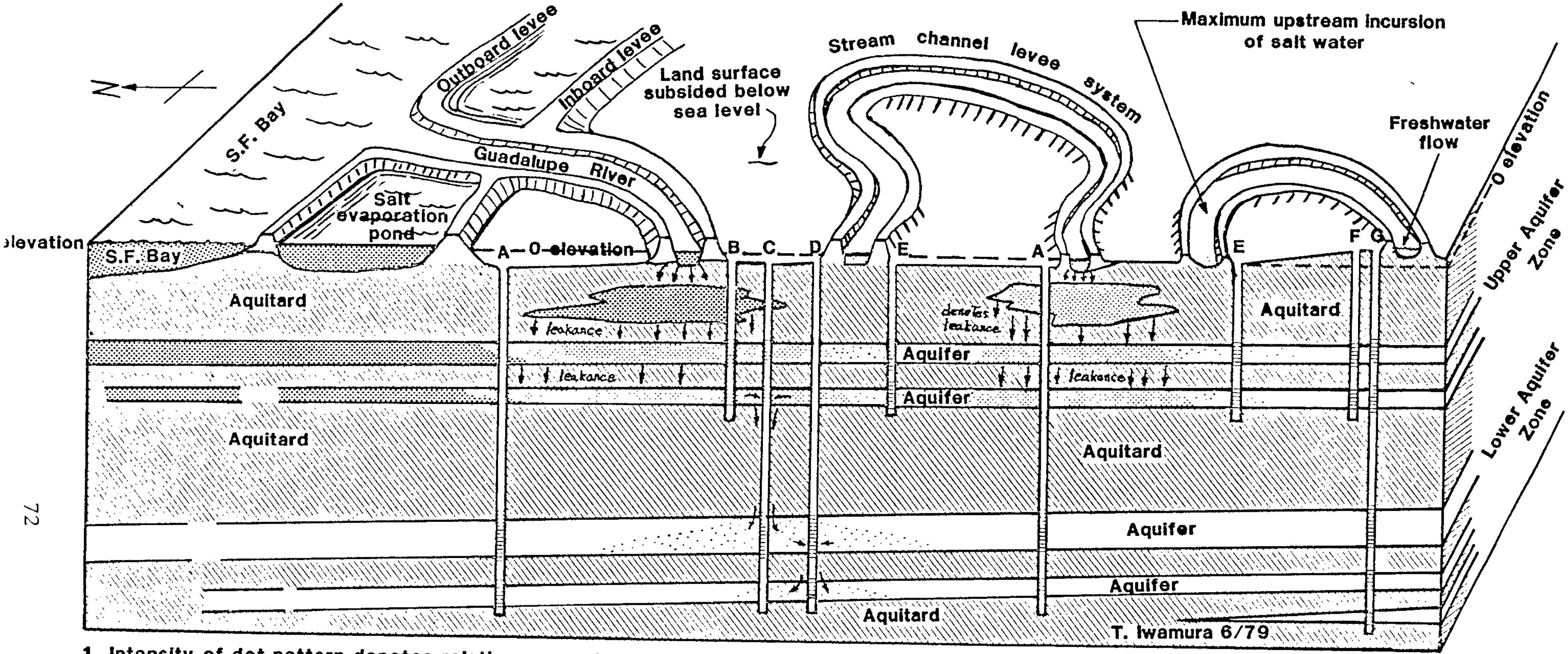
Contaminating saltwaters that incurred upstream would then be drawn into the upper aquifers through the leaky clay cap and intervening clay beds by downward hydraulic gradients created by pumping of the upper aquifer zone. Pumping would create a general lowering of the piezometric surface and would also create a temporary local cone of depression creating a sufficient downward gradient to overcome the low permeability of the clay beds. Ease of entry through the clays would be facilitated where the claybeds are thin (either naturally or artificially by channel deepening) or where the clays are more permeable. The presence of wells perforated in several aquifers or wells with deteriorated well casing can also facilitate vertical movement of contaminating waters more directly to the various aquifers below. As the contaminants enter the aquifer, they are more free to migrate in response to hydraulic gradients, largely controlled by pumping.

The time/chloride-content graphical plots (Plate 9) of well waters pumped from the shallow aquifer zone indicate that most of the saltwater is drawn into the aquifers during the pumping season as the highest chloride content occurs toward the end of the agricultural pumping season in the fall. This is also the time of the year when the greatest salt concentration occurs up the streams as the incurring Bay waters are not diluted by natural runoffs.

A diagrammatic depiction of the interpretive mechanism of intrusion south of Alviso is shown on Figure 8. This figure also shows the interpretive mechanism of intrusion into the lower aquifer zone.

Upper Aquifer Zone Saltwater Contamination in the Palo Alto Bayfront

The occurrence of highly concentrated saltwaters in a localized area within the upper aquifer zone along the present Palo Alto bayfront represent an anomaly. As the salty groundwaters are by far saltier than Bay water, this occurrence implies that the waters had undergone a process of salt concentration. Interestingly, the highest concentrations are located a short distance inland from the present bayfront levee. The



1. Intensity of dot pattern denotes relative concentration of salts in water.

"A" Wells : Perforated only in lower aquifer zone ; no water quality impairment ; previously flowing artesian wells.

"B" Well : Perforated in upper aquifer zone ; water quality impairment of aquifer by salt water intrusion.

"C" Well : Compositely perforated in upper and lower aquifer zone ; contamination of lower aquifer zone resulting from interaquifer transfer of water.

"D" Well : Perforated in lower aquifer zone ; water quality impaired from interaquifer flow occurring in well C.

"E" Wells : Perforated in upper aquifer zone ; water quality slightly impaired as wells are located farther from sources of intrusion.

"F" Well : Perforated in upper aquifer zone ; water quality unimpaired as well is beyond zone of intrusion.

"G" Well : Compositely perforated well ; water quality unimpaired by intrusion.

FIGURE 8. DIAGRAMMATIC INTERPRETATION OF SALT WATER INTRUSION SOUTH OF ALVISO

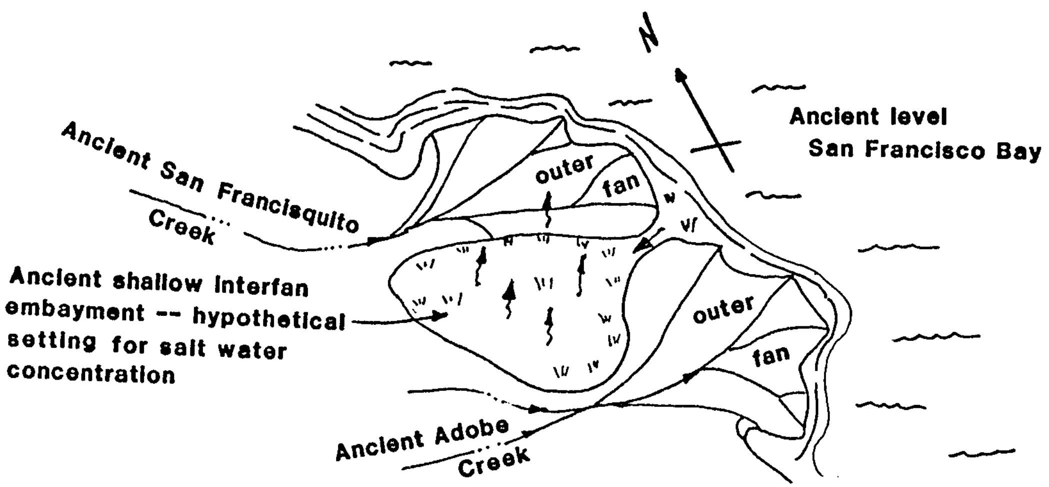
FIGURE

high concentrations occur in both the 20-foot and 45-foot aquifer zones with the higher concentration occurring in the 45-foot zone.

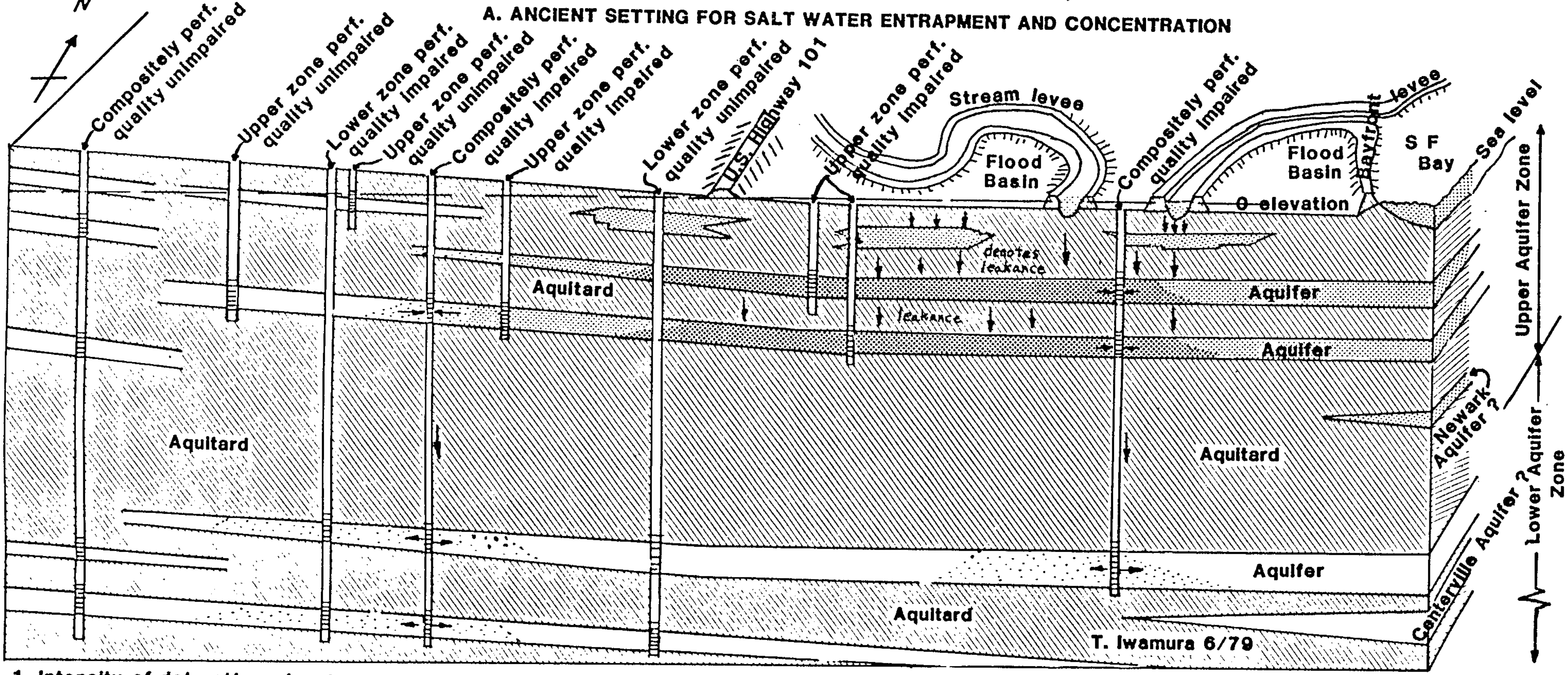
It is not known for certain if this area of high concentration was or was not a site of an old solar salt evaporator pond. Part of the overlying property was purchased by the City of Palo Alto from the Leslie Salt Company. After briefly checking the history of the area, Leslie Salt Company's operation, and the surficial appearance of the site, the author doubts that the area was a saltwater evaporator pond site. Leslie Salt Company's Number 1 pond, where the Bay water intakes are located and as a consequence the pond with the lowest salt concentration, is located east of Charleston Slough, which is east of the highest concentrated saltwater area. Furthermore, if the site were an old solar saltwater evaporator pond, it would seem logical that the 20-foot aquifer would be saltier than the 45-foot aquifer zone, which is not the case, unless the 20-foot aquifer were subsequently diluted by freshwater as a consequence of the operation of the Palo Alto Flood Basin which currently overlies a portion of the area.

Another possible explanation, and perhaps a more plausible one, is that the site may have represented a shallow interfan embayment of the Bay during periods in the geologic past which allowed saltwaters to naturally concentrate due to poor circulation and evaporation. The causes for the shallow embayment may have been the buildup of outer fan materials of San Francisquito Creek forming the northern boundary and Adobe Creek (Charleston Slough) forming the southern boundary, although the southern boundary of the high concentration has not been definitely established. Refer to Figure 9 for a diagrammatic depiction of the hypothetical setting for saltwaters to concentrate.

Subsequently these concentrated salty waters were buried under a clay layer as Bay levels rose, entrapping the salts. The thin aquifers contained in the buried sequence may represent unflushed small, local stream channels. The sequence of entrapment may have occurred twice in the geologic past. This highly concentrated saltwater occurrence would then represent entrapped connate water rather than a classical case of saltwater



A. ANCIENT SETTING FOR SALT WATER ENTRAPMENT AND CONCENTRATION



1. Intensity of dot pattern denotes relative concentration.
2. Impairment denotes water quality degradation caused by intrusion.

B. DIAGRAMMATIC PROFILE DEPICTING INTERPRETIVE MECHANISM OF INTRUSION

FIGURE 9. HYPOTHETICAL SETTING FOR SALT WATER CONCENTRATION AND MECHANISM OF INTRUSION , PALO ALTO BAYFRONT AREA

intrusion. The distinction, except for the difference in concentration, would be a rather academic matter as, in either case, the salty waters would have the potential to migrate in response to an inland, or reverse, hydraulic gradient. An aureole of lower concentrated water has been noted inland and to the northwest and southeast of the area of high concentration, representing a mixed transition water with native fresh groundwater.

The interpreted intrusive mechanism of the mobilization of the salty water inland in the upper aquifer zone and subsequently into the lower aquifer zone is diagrammatically depicted also on Figure 9. Areas adjacent and to the northwest and southwest of the local highly concentrated saltwater area may represent conditions of shallow aquifer zone intrusion suspected to be similar to that described for the area south of Alviso.

Shallow Aquifer Zone Southeast of Palo Alto

Local areas adjacent to or just beyond the intruded zone southeast of downtown Palo Alto contain freshwater with chlorides just exceeding 100 mg/l chloride in the uppermost aquifers. These were noted in shallow wells whose depth is above sea level and water tapped by them would not normally be subject to saltwater intrusion. A likely explanation is that these shallow aquifers have been degraded by irrigation return waters leaching salts into the aquifer upon pumping. This hypothetical concept is supported by the character depiction of short-term time/chloride-content plot for well 06S02W06P14 which is located at an elevation of approximately 17 feet and whose total depth is 16 feet. The period of record is from winter of 1974 to the present and is shown as Figure 10. The sharp confirmed rise in chloride content in the winter and spring of 1978 indicates leaching waters moving into the near surface aquifer, this following a drought period which spanned from the spring of 1975 to the winter of 1977-78.

In numerous other examples, but located much farther inland and at higher elevations, local groundwaters containing higher than 100 mg/l of chloride have been

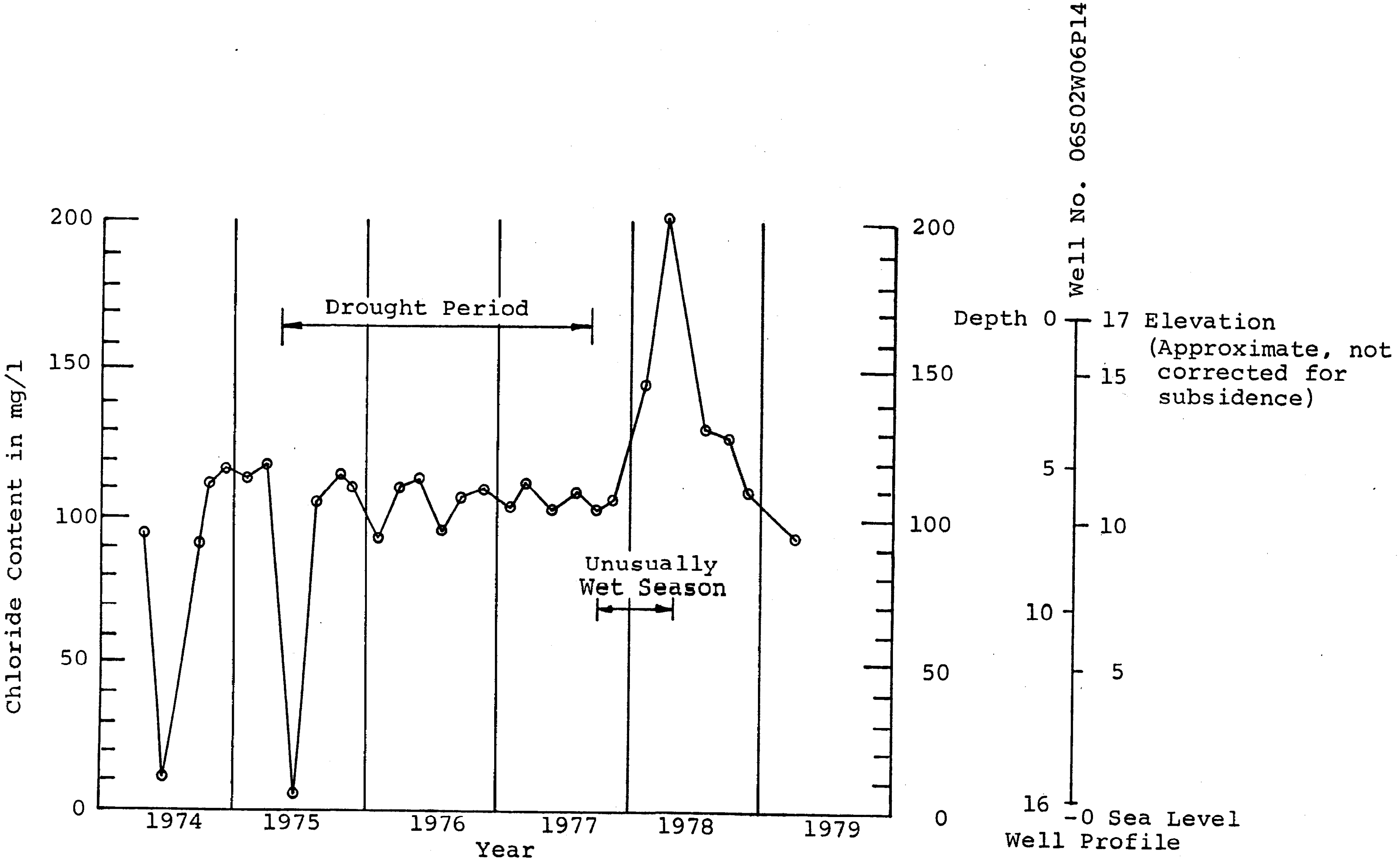


FIGURE 10. TIME/CHLORIDE-CONTENT PLOT FOR WELL **06S02W06P14** ILLUSTRATING GROUNDWATER DEGRADATION BY LEACHING

cited. Hence the 100 mg/l chloride content used as a criterion to denote saltwater intrusion only applies to areas adjacent to the Bay where physical (mainly topographical) conditions prevail that can potentially promote saltwater intrusion from the Bay under favorable conditions. Even this must be tempered with judgment as based upon review of evidence available.

Lower Aquifer Zone

The area of intrusion of the lower aquifer zone is much smaller and the severity of intrusion is much milder than the intrusion in the upper aquifer zone. The lower intruded areas generally occur beneath the principal zones of intrusion in the upper aquifer zone but in local areas the intrusion extends farther inland than that of the upper aquifer zone. This latter feature can be expected as these aquifers are at lower elevations below sea level than the upper aquifers. Another difference in the areal pattern of the lower zone intrusion is that local isolated areas of intrusion occur or have occurred in the past. These isolated local patterns suggest contamaination from local point sources.

As previously noted in Chapter II under the section on groundwater geology, the occurrence of a large area of once flowing artesian wells completed in the lower aquifer zone in the baylands strongly implies that the intervening clay bed that separates the upper and lower aquifer zone is essentially impervious. This is further substantiated by 1) the historic occurrence of freshwater in the lower aquifer zone beneath the middle of South San Francisco Bay, 2) by the controlled pump-out aquifer testing of well 05S02W31K13 performed for the Santa Clara Valley Water District hydraulic saltwater barrier project at Palo Alto, 3) by the wide seasonal variation in piezometric levels in water wells, and 4) by the high tidal efficiency noted by piezometric pressure responses in well 05S02W21L01 located in the middle of South San Francisco Bay.

The time/chloride-content plots indicate intrusion in the lower aquifer zone is or has been generally mild but with occasional erratic high seasonal peaks. These suggest that the intrusion occurred as slugs of contaminating waters entering the aquifers on a seasonal basis. Correlation of the periods of intrusion with the piezometric levels is good, with the intrusion occurring during the long-term lows of the piezometric levels. Individual seasonal peaks in chloride content also generally correlated with the seasonal pumping period or annual piezometric lows.

All of the foregoing observations point to water wells as being the avenues for intrusion into the lower aquifer zone with the contaminating waters either entering from the upper aquifer zone or from the surface. This would occur in response to drawing down the peizometric surface upon pumping as to create a downward hydraulic gradient.

In cases where wells are constructed in the tidal marshes, intrusion could occur from the surface through the well. An example of this is the Ravenswood wells located in the San Mateo County marshlands near East Palo Alto. These wells were only perforated in the lower aquifer zone and, hence, the source of the contaminants would be from the surface. However, intruded waters could have entered from the upper aquifer zone through wells if the well casing had deteriorated through disrepair. In the case of the Ravenswood wells, these were not sealed immediately after abandonment. The eventual method of sealing may also be subject to question.

Other ways the intruded upper aquifer zone waters can enter the lower aquifer through wells are by compositely perforating the casing in both zones or by constructing a gravel pack well whereby the annular gravel envelope placed around the casing serves as an avenue for water transfer. After the contaminated waters enter the lower aquifer, they become diluted by native groundwater and their movement within the aquifer is controlled by piezometric gradients. Refer also to Figures 8 and 9 for the diagrammatic depiction of the interpretive intrusion mechanism into the lower aquifer zone.

Proper well construction, proper sealing of abandoned wells immediately after abandonment and proper well maintenatnce can prevent intrusion into the lower aquifer zone. The first two items have been adopted in a countywide well standard ordinance (Appendices A and B.). Obviously these methods of prevention can only be applied to known existing wells in the bayland. Of the many old wells that are still presumed to exist, their location and conditions are not known at this time.

Another possible source of the contamination of the lower aquifer zone might be from rising connate water from salty zones beneath the freshwater zone. One such noted occurrence was detected at the bottom of a test hole drilled at the old Los Altos sewage treatment plant in the spring of 1958. This test hole was drilled to a depth of 910 feet. As the materials in the lower zones are strongly stratified with massive aquitards, occurrences of rising connate water would have to be through wells upon pumping of the freshwater zone; such a mechanism would also be consistent with the time/chloride-content plot character. However, it is strongly suspected that the areas of intrusion of the lower aquifer zone, as delineated for this study, are contaminated by flows from the upper aquifer zone or surface sources. This conclusion is based upon the proximity in relationship of their occurrences and upon the resulting mineral quality of the mildly intruded waters of the zone which represents a mix of native waters of the zone and contaminated upper aquifer zone waters as previously discussed under "Geochemical Aspects of Intrusion".

CHAPTER V.

PERSPECTIVE ON THE FUTURE OF INTRUSION

At present the condition of saltwater intrusion is either improving or static in most areas of both the upper and lower aquifer zones as pumping in the upper aquifer zone is gradually being reduced and the long-term piezometric levels of the lower aquifer zones have been in a gradual recovery trend in the past 8 to 12 years. These conditions can change if demand for groundwater in the baylands increase in the future.

The greatest threat leading to a worsening of the present status of intrusion is the resumption of land surface subsidence. This could result from increased pumping of the lower aquifer zone, depressing the piezometric levels to near their previous record lows of the mid 1960's. The resumption of land surface subsidence would farther depress the baylands below sea level. Flooding of these areas is prevented by a levee system. The recurrence of land surface subsidence would promote farther inland incursion of saltwater up stream channels, allowing additional lands to come in contact with the contaminating waters.

It is doubtful that the large mixed transition zone will enlarge significantly as pumping from the upper aquifer zone is being reduced. Wells affected by intrusion are being abandoned and replaced by deeper wells pumping out of the lower aquifer zone. This relief on pumping groundwater from the upper zone will reduce the groundwater level drawdown and higher water levels will reduce the amount of intrusion.

As long as the overlying upper aquifer zone contains saltwater, the potential of intrusion into the lower aquifer zone will persist. If piezometric levels in the lower aquifer zone are drawn down sufficiently, saltwater from the upper zone can be transferred from the upper to the lower aquifer zone through improperly constructed, abandoned, sealed, or maintained wells. The demand for groundwater from the lower aquifer zone is expected to continue to be significant in the long-term future.

Proper management of the groundwater basin will minimize lowering of the piezometric surface and the consequence of land surface subsidence. This not only prevents additional seawater intrusion, but also minimizes other adverse environmental consequences such as the potential for saltwater and freshwater flooding in the baylands area, damage to well casings, alteration of stream channel gradients, and alteration of gravity flow hydraulic structures. Significant lowering of the piezometric surface may also increase the potential for degraded connate waters in the deep sediments underlying the basin to rise into the freshwater zone.

CHAPTER VI.

RECOMMENDATIONS

Numerous actions can be proposed but a reasonable plan must consider economy and the estimated future use of groundwater. Implementation of a recommended program would depend on the results of the monitoring program which would portray changes in seawater intrusion.

General Priorities

1. Proper basinwide management is required to maintain adequate groundwater supplies and prevent adverse conditions. Basinwide management is important as the various segments of the basin are interconnected and a stress in one area could affect adjacent areas. The principal management considerations include recognizing and controlling long-term basin overdrafts which could eventually cause the resumption of land surface subsidence and protecting the quality of the groundwater resources.

2. The current salinity monitoring program in the Santa Clara County baylands must be continued. Basin management actions require definitive data, including both groundwater levels and quality data. Sequential data should be plotted against time so that past conditions, present status, and future projections can be observed. These become particularly significant when deterioration or degradation of groundwater levels and quality are involved. Remedial action should be instituted as early as possible before any developing problem becomes extensive and permanent. Protecting and preserving resources are far more economical than the difficult task of aquifer cleanup or reclamation.

3. Water well construction and sealing of abandoned well standards ordinance (SCVWD Ordinance 75-6, adopted in 1975) must be strictly enforced. The baylands falls into Water Quality Zone 2 of the ordinance, an area of potential threat to groundwater quality by encroaching saltwater from San Francisco Bay. This Zone includes areas

where intrusion has already occurred and areas where potential intrusion might occur. The principal objectives of this ordinance for Water Quality Zone 2 is to prevent contaminated surface water from entering shallow aquifers and to prevent interaquifer flow of water from the upper aquifer zone to the lower aquifer zone as a consequence of the construction or existence of a well. Compliance with the well standards will prevent this form of contamination of aquifers.

Proper maintenance of water wells is important. Deteriorated well casings present the potential for contamination and intrusion to occur. Therefore, wells must be maintained in good condition by periodic inspection and repair.

Other Considerations

1. It is recommended that the SCVWD actively participate in locating improperly destroyed abandoned wells and having them sealed and in locating defective or improperly constructed wells so that they can be corrected. Such a program would require a field canvass of the intruded area. This program can be staged to canvass the critical areas initially, followed by searches in the less critical areas.

2. It is recommended that the District investigate the feasibility of constructing tide gates or barriers at the mouth of certain critical streams. Tide gates near the bayfront would prevent the inland tidal incursion of saltwater along the stream channels which have been depressed below sea level by land surface subsidence. Such an investigation should consider need and the economic, physical, and environmental aspects in reaching a conclusion. Streams that should be considered are the Guadalupe River, Stevens Creek, and San Francisquito Creek. Critical times for stream barrier operations would be during the non- or low-flow months, when tidal incursion is not diluted by natural runoff. These months are also the period when much of the pumping occurs, resulting in lower groundwater levels and the potential to draw salty water into the aquifers.

At this time, it appears that the operation of the existing Standish Dam on Coyote Creek has had a constructive effect in preventing or alleviating saltwater intrusion into upstream areas.

3. If the District were to consider expansion of its hydraulic saltwater intrusion barrier, it is recommended that a detailed economic, geologic, engineering, and environmental investigation be performed. Such an investigation has to consider balancing the need against cost for the specific physical conditions. Detailed site exploration would be required as a part of the investigation. If the barrier is constructed, a system of monitoring wells should be installed to test its effectiveness.

Other facets to be considered in the study are the possible effects on the aquifer permeability if freshwater is reintroduced into the intruded aquifer and the cost of well field operations and maintenance, including injection well redevelopment.

Recommendations Regarding The Present Salinity Monitoring Program

The following specific recommendations are proposed to improve the present salinity monitoring program. When incorporated into the program, it will provide more definitive data and permit better scoping out of the extent, severity and implications of the seawater intrusion problem for the future.

1. It is recommended that a quarterly frequency of sampling salinity test wells be adopted. The newly constructed monitoring wells drilled by the District should be monitored bimonthly until one year's record is collected, in order to evaluate the range of seasonal fluctuations. The frequency of sampling is determined by the rate at which changes take place in the water sampled. Seasonal variations have been noted in wells in the current program. With this type of data on hand and some knowledge on how to interpret these fluctuations, a further reduction in sampling frequency may be justified.

2. It is recommended that static water levels be measured in the wells before turning on the pump for sampling. The data reviewed for this study indicated the existence of a correlation between water levels and chloride content.

3. The current salinity monitoring program field test includes only temperature while laboratory tests include pH, specific conductance, and chloride content. The field test program for the newly constructed wells includes, in addition, field measurements of specific conductance and pH. It is recommended that the level of laboratory testing be maintained but field test of all monitoring wells should also include temperature, pH and specific conductance.

4. Whenever an additional well is added to the monitoring program, a complete mineral analyses of the major constituents in groundwater should be performed. This is to determine the mineralogical character of the local groundwater for background and interpretive purposes and to prove the suitability of the monitoring well as a reliable source of data. Thereafter, analyses could be reduced to the interim constituents in the sustaining program.

5. It is recommended that the wells listed on Table 6 (approximate locations are shown on Plate 16) be added to the salinity monitoring program. These wells exist and could be added economically to the program. Details related to aquifer zones sensed by the wells, the well owner, available well construction data, and recommended frequency of sampling are noted in Table 6.

6. The following areas are recommended for the establishment of additional data points. These areas, as also shown on Plate 16, should be field canvassed to locate a suitable well. A suitable well to monitor the upper aquifer zone (less than 150 feet in depth) should be located in the following areas:

A. Along Coyote Creek between Alviso-Milpitas Road to Montague Expressway

B. Along Bowers Avenue between Mountain View-Alviso Road to about two miles south

C. Within or near Moffett Field Naval Air Station

TABLE 6

SUMMARY TABULATION OF RECOMMENDED WELLS TO BE ADDED TO SALINITY MONITORING PROGRAM

Well Number *	Other No.	Owner	Total Depth in feet	Perforated Depth Interval in feet	Remarks
To Monitor Upper Aquifer Zone					
05S02W34N01		Calif. State D.W.R.	84	77-82	Sample annually
06S01W05L01		Leslie Salt Co.	81	-	Sample annually
Unassigned	S4D	SCVWD	73	60-63	Sample quarterly
Unassigned	S9D	SCVWD	57	43-47	Sample quarterly
Unassigned	S24D	SCVWD	49	41-44	Sample quarterly
Unassigned	I-A	City of Mt. View	70	50-70	Sample quarterly
Unassigned	II-A	City of Mt. View	70	50-70	Sample quarterly
Unassigned	III-A	City of Mt. View	80	60-80	Sample quarterly
To Monitor Lower Aquifer Zone					
05S02W31J04	D3-3	SCVWD	209	201-204	Sample quarterly
05S02W31K13	I1-Deep	SCVWD	200	185-195	Sample quarterly
05S02W32F10	Duck Pond	City of Palo Alto	230	185-198	Sample quarterly
05S02W34N02		DWR	184	177-184	Sample annually

TABLE 6 (continued)

SUMMARY TABULATION OF RECOMMENDED WELLS TO BE ADDED TO SALINITY MONITORING PROGRAM

Well Number *	Other No.	Owner	Total Depth in feet	Perforated Depth Interval in feet	Remarks
			To Monitor Lower Aquifer Zone (continued)		
05S03W25M04		Palo Alto Mutual W.C.	306	219-279	Sample quarterly
05S03W25M05		Palo Alto Mutual W.C.	260	188-251	Sample quarterly
05S03W35G10	Hale	City of Palo Alto	934	102 840	Sample quarterly
06S01W05L02		Leslie Salt Company	250	-	Sample annually
06S01W05L03		Leslie Salt Company	330	-	Sample annually
06S02W05Q03	D2	SCVWD	193	178-183	Sample quarterly
06S02W06H02	D1	SCVWD	193	178-183	Sample quarterly
06S03W01D10	Middlefield	City of Palo Alto	750	165 192	Sample quarterly
Unassigned	III-B	City of Mt. View	190	170-190	Sample quarterly

* Refer to Plate 16 for approximate well location.

A suitable well to monitor only the lower aquifer zone (only perforated at depths below 150 feet) should be located in the following areas:

A. Along Bayshore Freeway between University Avenue and Embarcadero Road

B. At Moffett Field Naval Air Station

C. Within one mile northeast of the intersection of Montague Expressway and Lafayette Street

7. There may be a possibility that some of the wells on the current or revised salinity monitoring program can be deleted. It is premature to make these deletions until the data obtained from the expanded program can be fully evaluated.

Recommendations Regarding Sampling Procedure

It is needless to say a "poor" sample or a nonrepresentative sample is a wasteful effort and could result in developing improper conclusions or taking inappropriate actions. In order to assure that samples obtained are representative and the circumstances regarding it can be unquestionably qualified, the following are recommended:

1. During sampling the field personnel should have in their possession the previous records (at least the previous two sampling analyses) so that quick comparisons of field tests can be made. If significant changes have occurred, the field personnel can either check their procedure or testing equipment or try to account for the change through their own field observations or to make inquiries with the owner (as to any changes in pumping operation, repairs, etc.). If the determinations are significant, an annotated comment would be ordered under "Remarks".

In the event that significant changes have occurred, or if any important interpretive need arises, a data point can be resampled and a complete mineral analysis of the principal constituents can be performed. These decisions should be left to the discretion of the reviewer.

2. As the well is being pumped during the sampling precedure, it is recommended that field personnel obtain periodic readings of the specific conductance and pH. Specific conductance and pH should be within a consistent range before obtaining the sample for laboratory testing. Wide changes in specific conductance during pumping usually implies changes are being caused by the varying mix of statified stagnant waters in the well casing (and gravel pack) with formation waters. Specific conductance usually begins to stabilize after waters from the formation are pumped. A high value of pH may reflect contamination from the concrete or cement grout annular well seal. The effects of this contamination can be eliminated by a longer period of pumping before the sample is obtained.

Sustaining Investigations and Future Budgeting

The foregoing recommendations include revising and sustaining the salinity monitoring program which is an important part of the District's groundwater basin management program. Although the addition of the recommended monitoring wells would increase the effort expended on the program, the increased effort would be somewhat offset by the recommended lower frequency of sampling. Eventually some of the monitoring wells may be deleted as results of the revised monitoring program are evaluated.

Continuous, timely, graphical presentation of data is required so that critical review of the information collected can be performed without delay. This is of particular importance considering that timely avoidance of a problem is a more economical solution than attempting to correct a problem.

Also, as previously recommended, a program for locating and properly destroying abandoned wells should be implemented as a staged program, designed to cover a limited area each year. The program should be continued until the areas in question are fully covered.

Other related activities that must be continued as supporting features of the District groundwater management program are groundwater level monitoring and implementation of the well standards ordinance. In turn, continuation of the salinity monitoring program would provide additional data and benefits to other District programs such as those pertaining to water quality, land use, wastewater reclamation, wastewater disposal, etc. Therefore, the revised salinity monitoring program, including interpretation of results, and the addition of abandoned well canvassing should be budgeted fully in future years.

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APPENDIX A

STANDARDS FOR THE SEALING OF ABANDONED WELLS SANTA CLARA COUNTY (ABRIDGED)

SCVWD ORDINANCE 75-6

PURPOSE

The purpose of standards for the sealing of abandoned wells is to protect and preserve the groundwater supplies for future uses and to eliminate the potential physical hazard that exists from wells that are not being used. This is to be accomplished by restoring, as nearly as possible, those subsurface conditions which existed before the well was constructed. Since subsurface conditions vary from place to place, such standards must be formulated so as to conform to the groundwater geohydrologic and water quality conditions of the specific areas within the groundwater basins of Santa Clara County.

WATER QUALITY ZONES

For well sealing purposes, the groundwater basins of Santa Clara County have been divided into three water quality zones, based on the different quality of waters present and on the local geologic conditions. Zone 1, which is the largest portion of the basin, represents the areas where the quality of water at all pumping depth intervals is generally good. Zone 2, near San Francisco Bay, is a multiaquifer area where the shallow zone (0 to 150 feet) may be contaminated or could become contaminated by seawater. In Zone 3, the Evergreen area, degraded quality water occurs below a depth of 300 feet with good quality water overlying this zone. These water quality zones are delineated on Figure 1.

WELL SEALING PROCEDURE

All "abandoned" wells shall be destroyed in such a way that they will not produce water or act as a channel for the interchange of water, when such interchange may result in deterioration of the quality of water in any or all water-bearing formations penetrated, or present a hazard to the safety and well-being of people and animals.

Zone 1

In Zone 1, where the quality of water is generally unimpaired, the objective of the sealing standard is to prevent contamination of the aquifer from surface sources. Here, a "general sealing standard" will apply which will entail the filling of the well with an impervious filler material (inorganic soils of low permeability, bentonite, concrete, or cement grout) from the bottom of the well to a depth of 50 feet. The upper 50 feet of the well shall be filled by the placement of cement grout, neat cement or concrete. Placement of the filler and sealing materials is to be performed in a manner that will prevent bridging, dilution or segregation of the sealing material (tremied into the well from the bottom). Placement of an annular grout seal in the upper 50 feet will be required if there is an annular opening or a gravel envelope around the well casing. Placement of the annular seal in the upper 50 feet, if necessary, shall be accomplished by either the removal of the upper casing or the perforation of the casing with the cement grout forced to pass into the annular opening or gravel pack. Typical general sealing features of a destroyed well are shown on Figure 2.

Zone 2

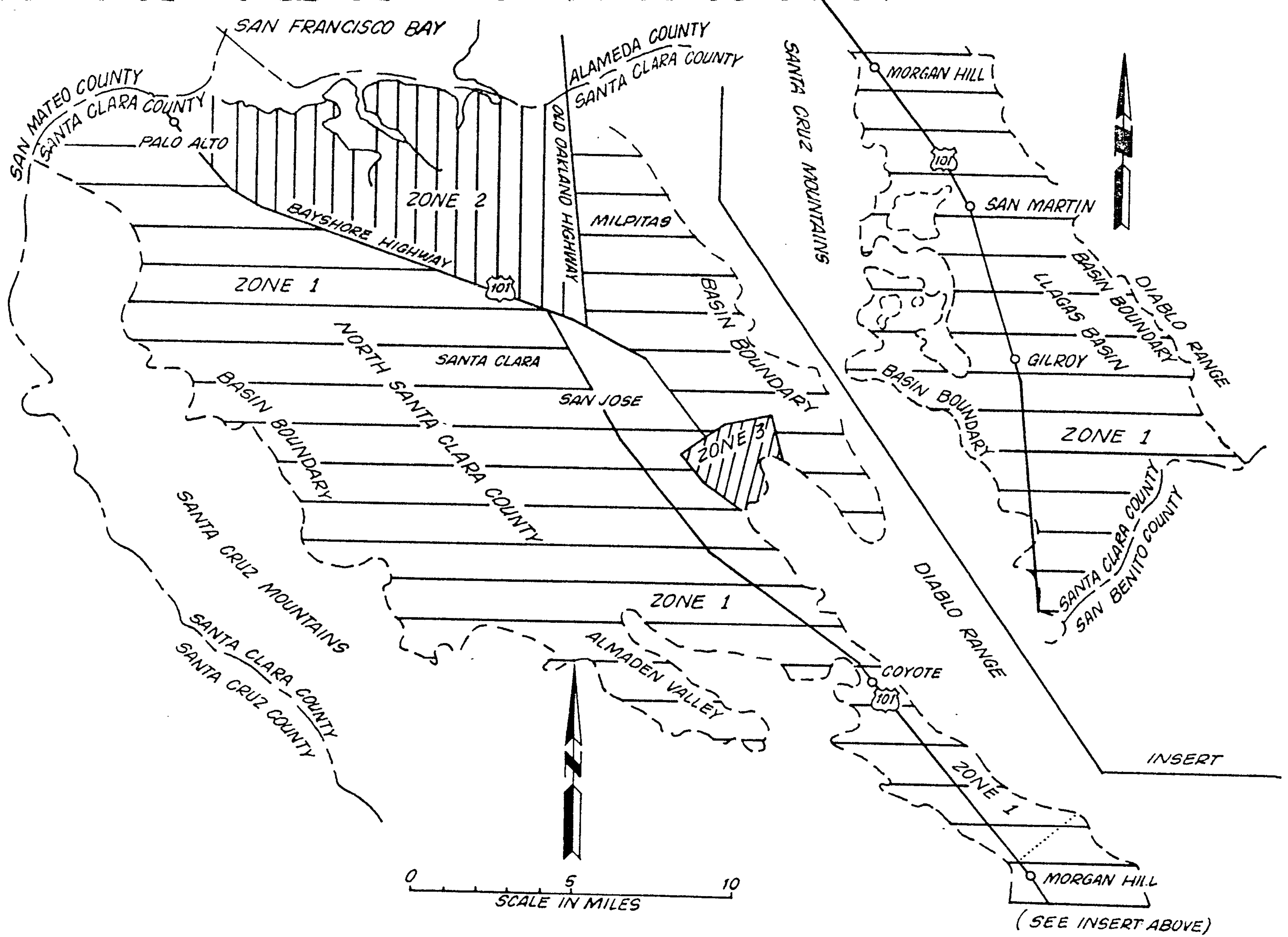
In Zone 2, adjacent to San Francisco Bay where degraded quality water occurs in the shallow zone to a depth of about 150 feet with good quality water in the lower aquifers, it is the objective of the well sealing standard to prevent inter-aquifer flows from the shallow aquifer into the lower aquifers through abandoned wells. In order to accomplish this, all the provisions stated under "general sealing standard" discussed under Zone 1 shall be employed plus the placement of an annular seal opposite a clay layer at a depth of about 150 feet. The annular seal is to be placed by perforating an interval not less than 10 feet at a depth of 150 feet, then filling the casing with cement grout and forcing the cement grout to flow into and seal the annular opening between the well casing and the clay formation or into and seal the gravel pack. Typical sealing features of a destroyed well for Zone 2 are presented on Figure 3.

Zone 3

In Zone 3, the portion of the Evergreen area where aquifers below a depth of 300 feet have yielded poor quality water, it is the objective of the well sealing standard to prevent interchange of water between the lower aquifers containing mineralized connate water and the upper unimpaired water quality aquifers. In order to accomplish this, all provisions stated under "general sealing standards" in Zone 1 shall be employed plus the placement of an annular seal opposite a clay layer at a depth of about 300 feet. The annular seal is to be placed in a similar manner as discussed under Zone 2 and the upper 300 feet of the well shall be sealed with concrete or cement grout. Typical sealing features of a destroyed well for Zone 3 are presented on Figure 4.

REFERENCE

Reference is made to the unabridged version of the Standards for a detailed account of the purposes, objectives, well sealing procedures, sealing materials, additional requirements in urban areas, definition of terms, bibliography, geology of the groundwater basin, water quality criteria, and other pertinent information. Said unabridged version is available for inspection in the District office.



GROUNDWATER QUALITY ZONES
SANTA CLARA COUNTY

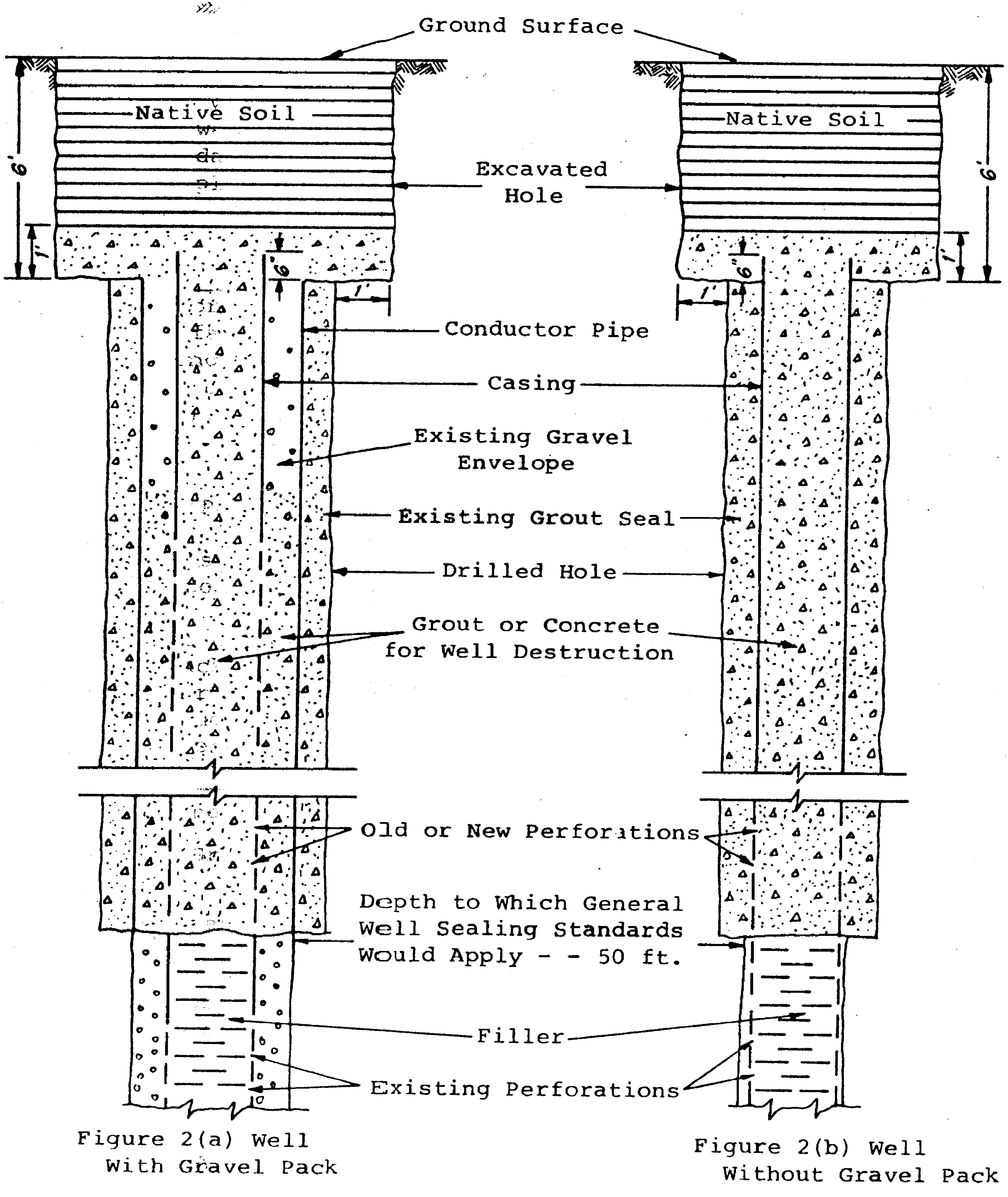
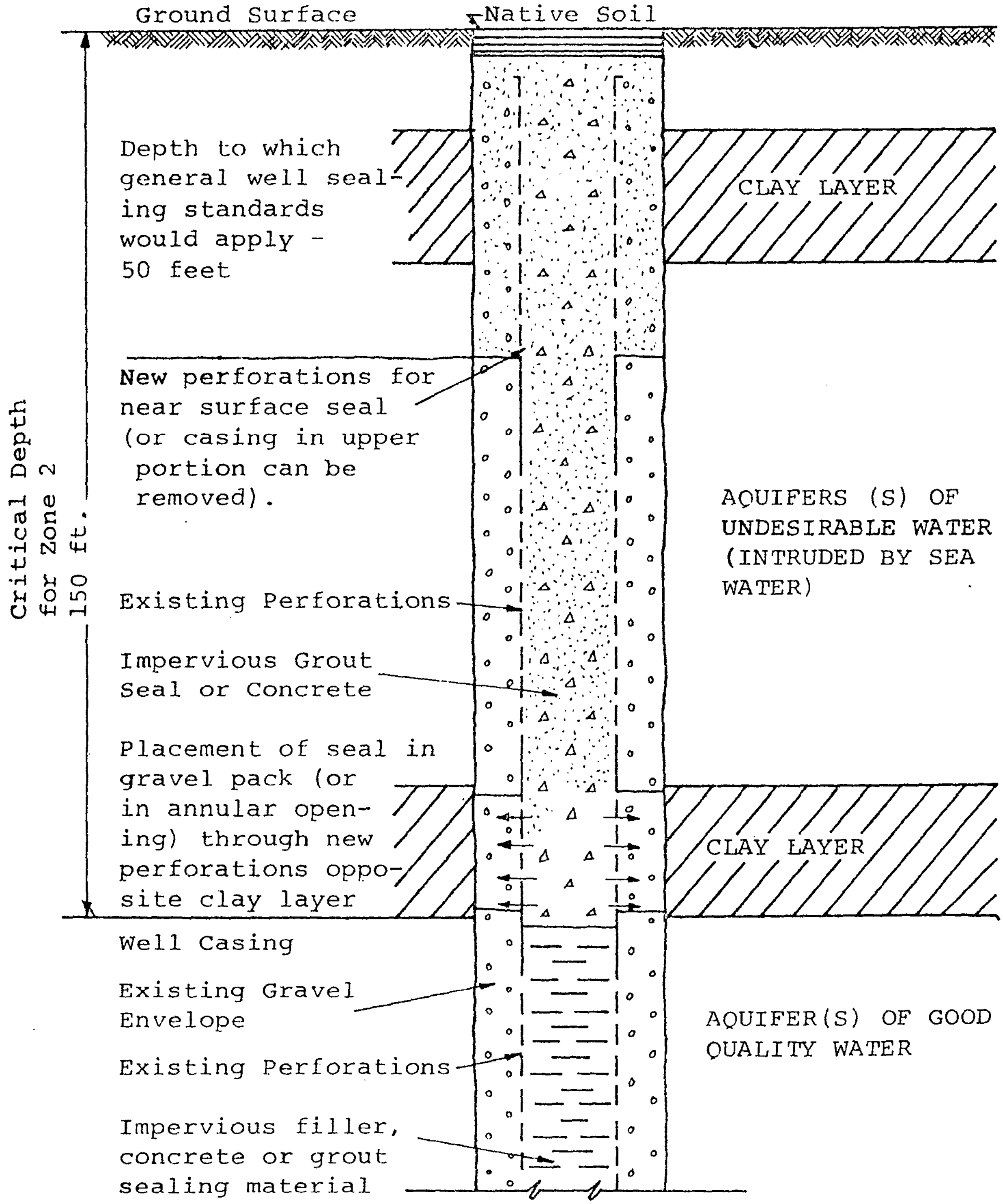


Figure 2(a) Well With Gravel Pack

Figure 2(b) Well Without Gravel Pack

NOT TO SCALE

FIGURE 2. TYPICAL SEALING FEATURES OF DESTROYED WELLS


Ground Surface
Native Soil
Depth to which general well sealing standards would apply - 50 feet
CLAY LAYER
New perforations for near surface seal (or casing in upper portion can be removed).
Critical Depth for Zone 2 150 ft.
AQUIFERS (S) OF UNDESIRABLE WATER (INTRUDED BY SEA WATER)
Existing Perforations
Impervious Grout Seal or Concrete
Placement of seal in gravel pack (or in annular opening) through new perforations opposite clay layer
CLAY LAYER
Well Casing
Existing Gravel Envelope
AQUIFER(S) OF GOOD QUALITY WATER
Existing Perforations
Impervious filler, concrete or grout sealing material

NOT TO SCALE

FIGURE 3. TYPICAL SEALING FEATURES OF DESTROYED WELLS FOR ZONE 2 (for gravel packed wells)

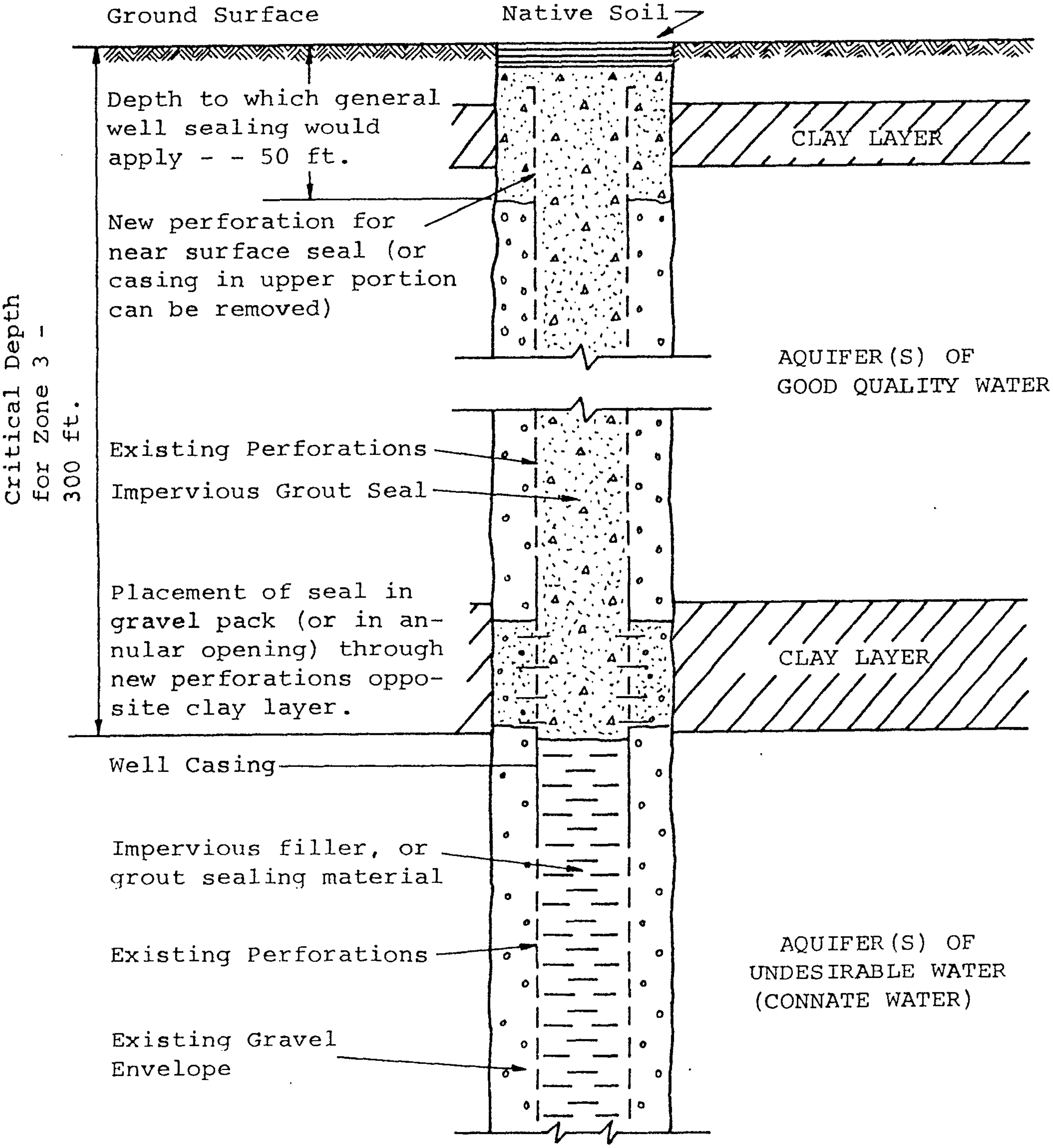

Ground Surface
Native Soil
Depth to which general well sealing would apply - - 50 ft.
CLAY LAYER
New perforation for near surface seal (or casing in upper portion can be removed)
Critical Depth for Zone 3 - 300 ft.
AQUIFER(S) OF GOOD QUALITY WATER
Existing Perforations
Impervious Grout Seal
Placement of seal in gravel pack (or in annular opening) through new perforations opposite clay layer.
CLAY LAYER
Well Casing
Impervious filler, or grout sealing material
Existing Perforations
AQUIFER(S) OF UNDESIRABLE WATER (CONNATE WATER)
Existing Gravel Envelope
NOT TO SCALE

FIGURE 4. TYPICAL SEALING FEATURES OF DESTROYED WELLS FOR ZONE 3 (for gravel packed wells)

APPENDIX B

STANDARDS FOR THE CONSTRUCTION OF WELLS SANTA CLARA COUNTY

(Abridged)

SCVWD ORDINANCE 75-6

PURPOSE

The purposes of standards for well construction are not only to provide adequate protection of water in wells but equally, if not more importantly, to protect and preserve the groundwater supply in aquifers for future uses. These purposes are to be accomplished by properly locating the well site, by requiring an annular seal in the upper portion of the well to prevent well contamination from surface sources, and by specifying construction requirements to prevent interaquifer transfer or mixing of degraded groundwaters with good quality waters through wells. Furthermore, wells properly constructed could be easily and adequately destroyed after their usefulness is over without having to resort to complicated and expensive procedures in order to protect the aquifers. The protection of groundwater supplies is a complex problem, and, although poor well construction may not be the principal cause of groundwater contamination, the problem of aquifer contamination must be attacked from all possible aspects.

WATER WELL LOCATION WITH RESPECT TO CONTAMINANTS AND POLLUTANTS

All water wells shall be located an adequate horizontal distance from potential sources of contamination and pollution. Most of the factors involved in determining safe distances are usually not known. The following distances, on the basis of past experience and general knowledge, are safe where dry upper unconsolidated formations, less permeable than sand, are encountered:

Sewer	50 feet
Subsurface sewage leaching field, septic tank, or pit privy	100 feet
Cesspool or seepage pit	150 feet

No water well shall be located closer than the above distances from the specified sources of contamination. Where, in the opinion of the enforcing agency, adverse conditions exist, the usual distances shall be increased or special means of protection shall be provided.

If possible, the well shall be up the groundwater gradient (upstream) from the specified source of contamination.

WATER QUALITY ZONES

Since subsurface conditions vary from place to place, the standards must be formulated so as to conform to the groundwater geohydrologic and water quality conditions of the specific areas within the ground water basins of Santa Clara County. For well construction and sealing purposes, the groundwater basins of Santa Clara County have been divided into three water quality zones. Zone 1, which is the largest portion of the basins, represents the areas where the quality of water at all pumping depth intervals is generally good. Zone 2, near San Francisco Bay, is a multi-aquifer area where the shallow zone (0 to 150 feet) may be contaminated or could become contaminated by sea water. In Zone 3, the Evergreen area, degraded quality water occurs below a depth of 300 feet with good quality water overlying this zone. These water quality zones are delineated on Figure 1.

The bedrock areas outside the groundwater basins have their individual potential problems and well construction requirements for these areas are also included in these standards.

WELL CONSTRUCTION REQUIREMENTS

All wells are to be constructed in such a way that they will not serve as a channel allowing surface waters to enter the groundwater body nor will they serve as a channel for interaquifer groundwater flow when such a flow may result in the deterioration of the quality in any or all water-bearing formations penetrated. The following paragraphs present examples of well construction standards that meet the protection objectives in the various water quality zones and in the bedrock areas. If the enforcing agency finds that compliance with any of the requirements prescribed herein is impractical for a particular location because of unusual conditions and would result in construction of an unsatisfactory well, the enforcing agency may prescribe alternative requirements which are equivalent to these standards in terms of protection obtained.

Zone 1

In Zone 1, where the quality of water within the groundwater basin is generally unimpaired, the objective of the construction standards is to prevent well and aquifer contamination from surface sources. Here, a "general construction standard" will apply which entails the requirement of an effective surface seal. This is to be accomplished by the placement of a neat cement, cement grout, or concrete seal in the annular space between the well and the wall of the drilled hole to a minimum depth of 50 feet below the surface. In stratified formations the seal should terminate in a clay or other impermeable material. Special sealing depth requirement on an individual basis will be set forth by the enforcing agency for application of wells to be constructed less than 50 feet in depth. The sealing material shall be applied from the bottom of the interval to be sealed to the top in a manner that will prevent bridging, dilution, or segregation of the sealing material (by employing either a tremie pipe or a pressure grouting method). The thickness of the seal shall be in accordance with the State of California Standards.

A concrete floor slab, or base, shall be constructed around the top of all pumping or injection wells. The top of the floor slab shall slope away from the casing and the outer edge of the slab shall be at least six inches above the ground surface.

For a pump above the surface, a concrete pedestal shall be constructed atop the floor slab on which the pump is to be placed.

Examples of acceptable sealing construction for Zone 1 for nongravel packed wells are shown on Figure 2 and for gravelpacked wells on Figure 3.

Zone 2

In Zone 2, adjacent to San Francisco Bay, degraded quality water occurs in the shallow zone to a depth of 150 feet with good quality water in the lower aquifers. The specific objectives of the well construction standards are to prevent interaquifer flows from the shallow aquifer into the lower aquifers through wells and, in addition, to meet the construction objective for Zone 1. In order to accomplish these, all provisions stated under "general construction standards" discussed under Zone 1 shall be employed plus the extension of the surface seal into a clay or other impermeable layer at a minimum depth of 150 feet. An example of acceptable well construction in Zone 2 is shown on Figure 4.

If a gravel packed well were to be constructed in Zone 2, the construction of an annular seal as shown on Figure 3 would have to be extended into a clay layer at a depth of around 150 feet.

Zone 3

In Zone 3, the portion of the Evergreen area where aquifers below a depth of 300 feet have yielded poor quality water, the specific objectives of the well construction standards are to prevent interchange of groundwater between the lower aquifers containing mineralized connate water and the upper unimpaired water quality aquifers, and also to meet the objective for Zone 1. In order to accomplish these, all provisions stated under "general sealing standards" for Zone 1 shall be employed plus limiting the depth of wells to be constructed to a maximum of 300 feet. An exception in regards to the maximum depth can be made if the owner can prove to the enforcing agency that waters at a greater depth are of good quality. This has to be based on the results of laboratory testing of a sample obtained only from the lower zone. In order to obtain such a sample, the lower zone shall be isolated from the upper zones during sampling.

BEDROCK AREAS

Bedrock areas present special conditions for the safe construction of water wells in that waters in bedrock could be, in part, recharged and transmitted unfiltered through open fractures. This is in contrast to the filtering that occurs as water is recharged and transmitted through unconsolidated granular materials of the groundwater basins.

For wells constructed in bedrock, the objective is to prevent contamination from surface sources, just as for wells constructed within the groundwater basin. This is to be accomplished by selecting the well site in a manner to obtain maximum security from potential sources of contamination and requiring the construction of an annular seal in the upper portion of the well.

In the selection of a well site, the conditions listed earlier under the heading "Water Well Location with Respect to Contaminants and Pollutants" shall be observed. In places where adverse conditions exist, the minimum distances listed shall be increased or special means of protection shall be provided.

In order to construct the upper annular seal, an oversize hole must be constructed to the depth and diameter required for the seal and casing installed to retain the seal. All public water supply wells including individual domestic wells to be constructed in bedrock in subdivided lands under the jurisdiction of the County Land Development Regulations shall incorporate at least a 50-foot annular seal from the surface. Public water supply wells constructed in bedrock are also subject to Environmental Health Services approval before being placed into service. For individual domestic wells on lands not subject to Land Development Regulations shall also incorporate a 50-foot annular seal from the surface unless these wells are less than 65 feet deep. For these wells, the annular space shall be sealed in the upper three-fourths of the depth of the well. All other requirements of the general well construction standards shall apply to wells in bedrock.

A typical example of an acceptable seal for well construction in bedrock is shown in Figure 5.

CATHODIC PROTECTION WELLS

Cathodic protection wells (or "deep anodes") also present hazards to groundwater quality just as a water well may in that both represent an opening from the surface through various aquifers. Just as for water wells, it is the objective of these standards to protect the quality of water in aquifers by requiring cathodic protection wells to be constructed in such a manner that they will not serve as a channel allowing surface waters to enter the groundwater body nor will they serve as a channel for interaquifer groundwater flow when such flow may result in the deterioration of the quality in any or all the aquifers penetrated. It is also the purpose of these standards to facilitate the effective sealing of these wells when their useful life has expired.

The sealing requirements for Zones 1 and 2 are similar to that of water wells constructed in these respective zones as illustrated in Figure 6, examples A and B, respectively (the latter, in Zone 2, if the well is deeper than 150 feet). In Zone 3, if the well is deeper than 300 feet, the annular seal would have to be extended to a depth of 300 feet as shown in Figure 6, example C, in order to protect the upper aquifers from rising waters from the degraded lower aquifers. If the cathodic protection well is to be less than 150 feet in depth in Zone 2 and less than 300 feet in Zone 3, general sealing requirements as for Zone 1 shall apply.

The top of the well shall be protected against the entrance of surface water draining from the surrounding land by installation of watertight caps, covers, plugs or similar devices. In drainage ways, exclusive of highways, streets, paved surfaces (such as parking lots, equipment yards, etc.), sidewalks, and the like, the top of the well shall terminate above, or otherwise be protected against, known conditions of flooding. When extended above ground surface, the vent pipe shall be terminated at the rectifier housing or other protective housing at an elevation which is above known conditions of flooding.

The diameter of the vent pipe is to be of sufficient size in order to be properly backfilled when the useful life of the anode has expired (sealing of an abandoned well).

DISINFECTION OF WELL

All public water supply, individual domestic, and industrial wells shall be disinfected following construction, repai or when work is done on the pum before the well is placed into service.

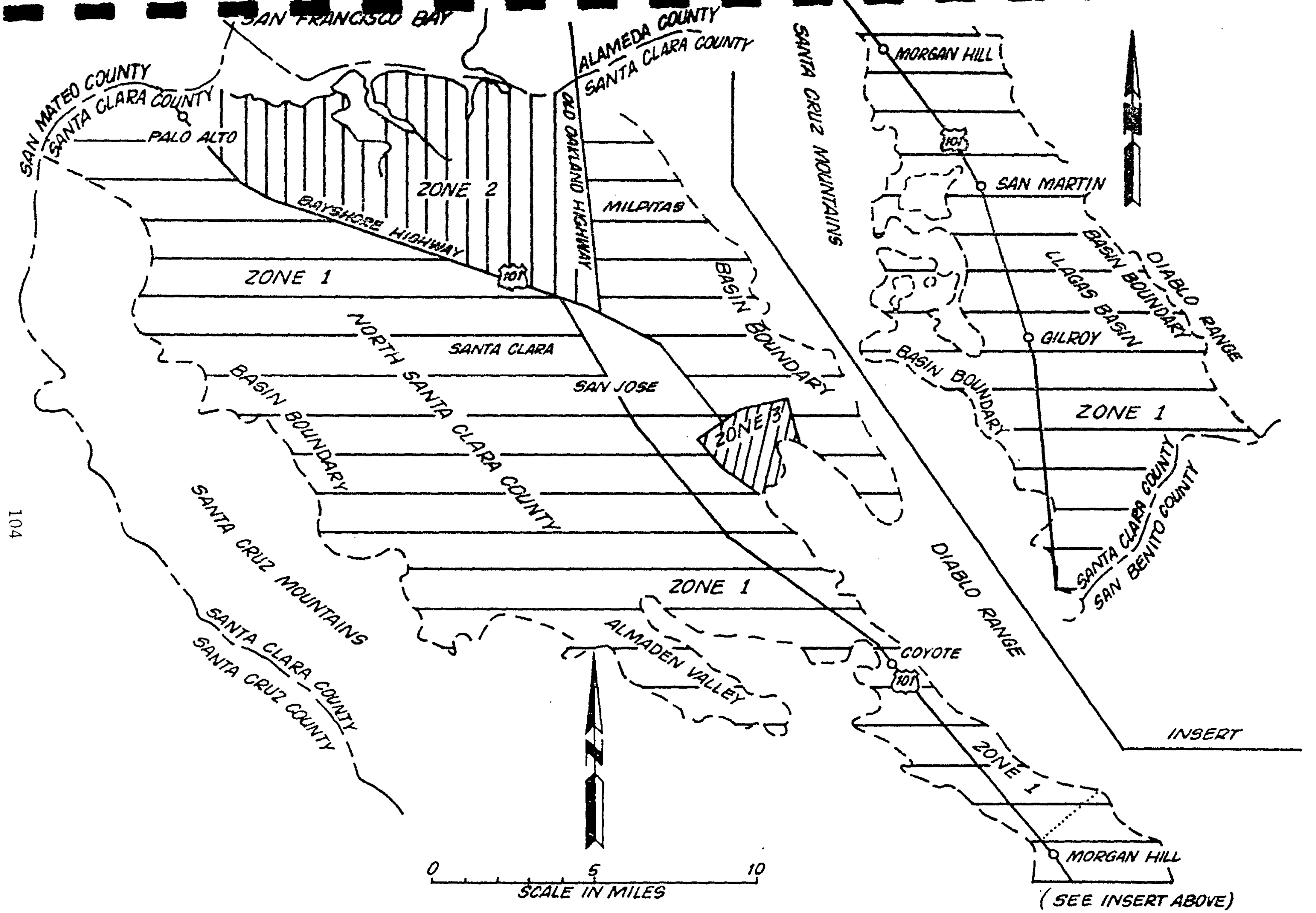
COMPLIANCE WITH STATE CODES

In complying with these standard the well driller must also comply to the provisions of the various State codes relating to water well drilling. Thes include provisions regarding Contractor License Law and the filing of notice of intent and well completion reports under the provisions of the Water Code.

REFERENCE

Reference is made to the unabridged version of the Well Construction Standards for a more detailed account of th purposes, objectives, and well construction requirements in addition to the bibliography and other pertinent information. The Well Construction Standards i one of two documents pertaining t water well ordinance, the companion document being "Standards for the Sealing of Abandoned Wells, Santa Clara County", October, 1972. The "Sealing Standards" also contain as Appendix A – "Geology", Appendix C – "Definition of Terms", and Appendix D – "Water Quality Criteria" which will not be repeated in the Well Construction Standards Document.

The general requirements along with specifications on procedure, materials, surface construction features, disinfection, water quality sampling, and other pertinent features conform to Chapter II of California Department of Water Resources Bulletin 74, "Water Well Standards State of California", February 1968, except where exceptions are noted in these Standards.



GROUNDWATER QUALITY ZONES
SANTA CLARA COUNTY

FIGURE 1

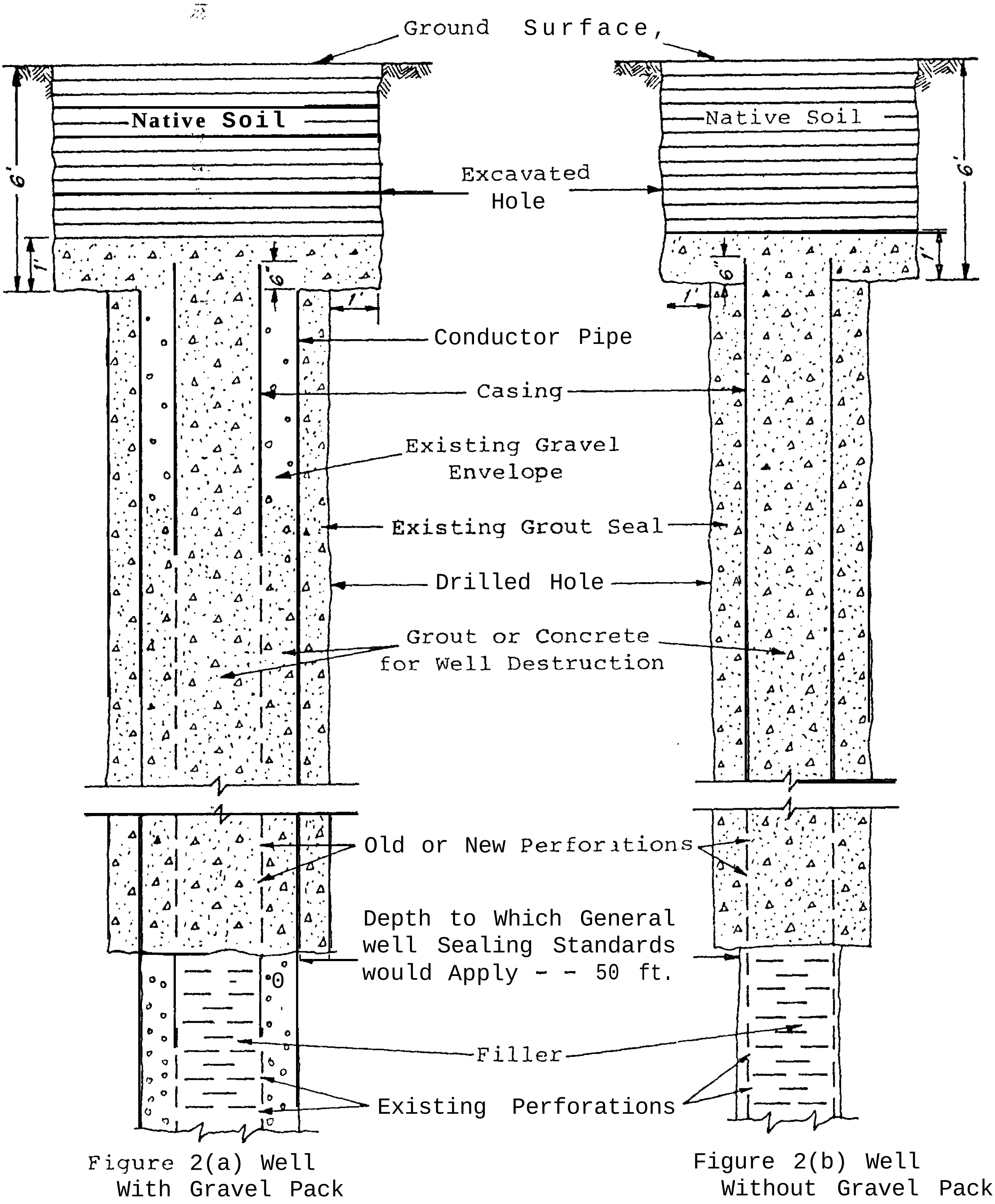
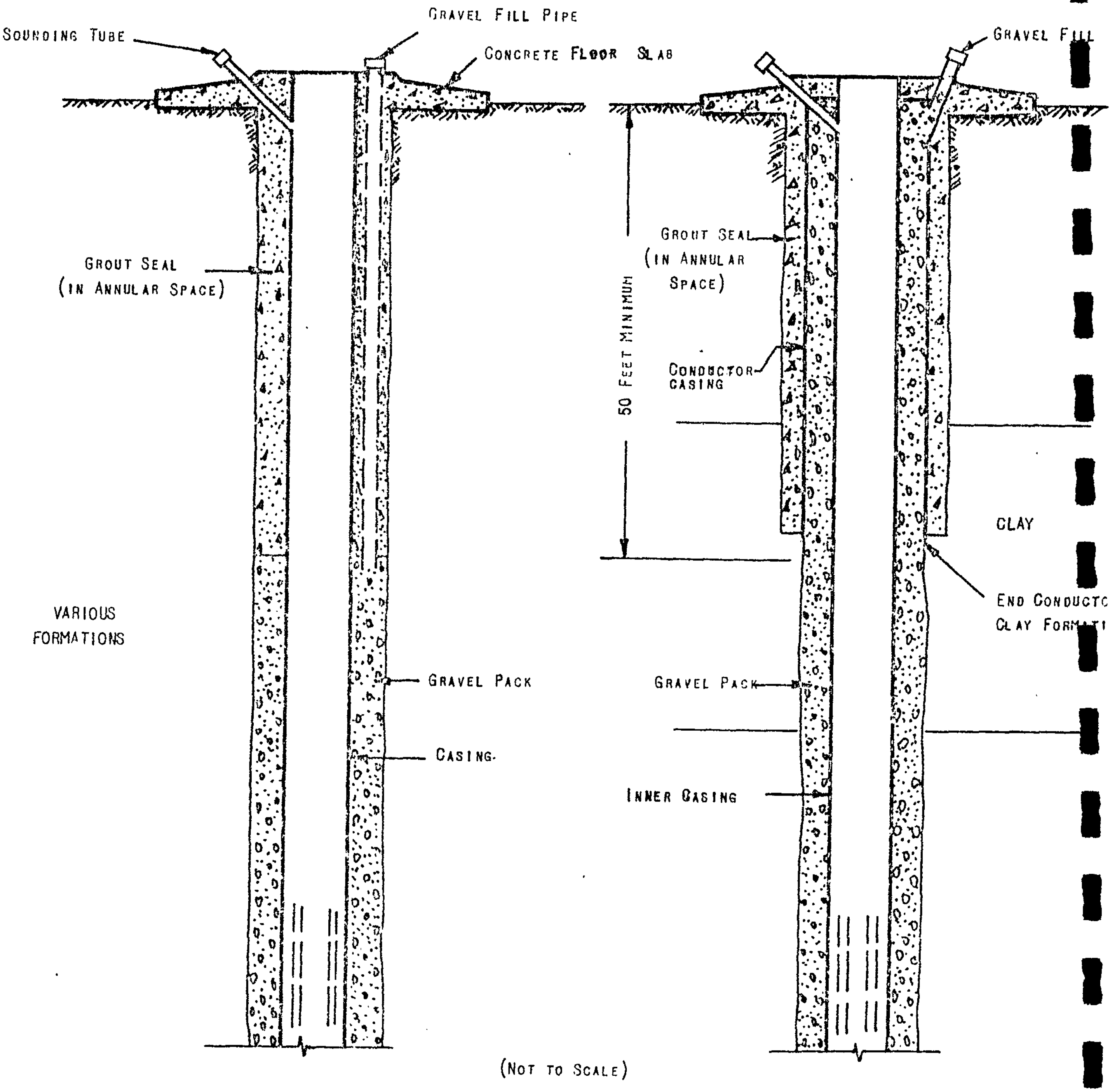


Figure 2(a) Well With Gravel Pack

Figure 2(b) Well Without Gravel Pack

NOT TO SCALE

FIGURE 2. TYPICAL SEALING FEATURES OF DESTROYED WELLS

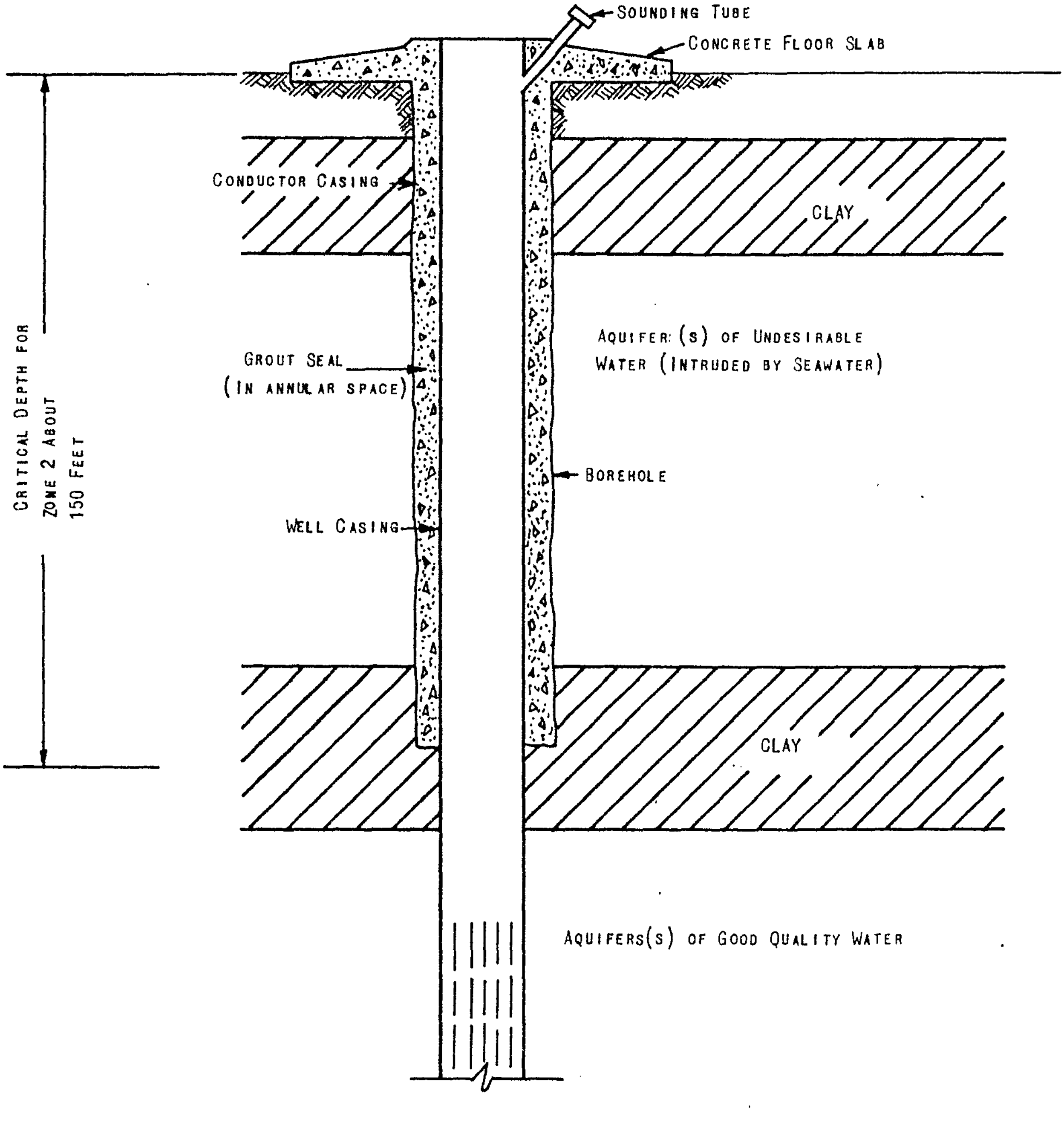


(Not to Scale)

A. Without Conductor Casing

B. With Conductor Casing

FIGURE 3. SEALING CONDITIONS FOR UPPER ANNULAR SPACE
GRAVEL PACKED WELLS


Sounding Tube
Concrete Floor Slab
Conductor Casing
Clay
Critical Depth for Zone 2 About 150 Feet
Aquifer (s) of Undesirable Water (Intruded by Seawater)
Grout Seal (In annular space)
Borehole
Well Casing
Clay
Aquifers(s) of Good Quality Water

(Not to Scale)

FIGURE 4. EXAMPLE OF SEALING UPPER AQUIFER ZONE WELL IN ZONE 2

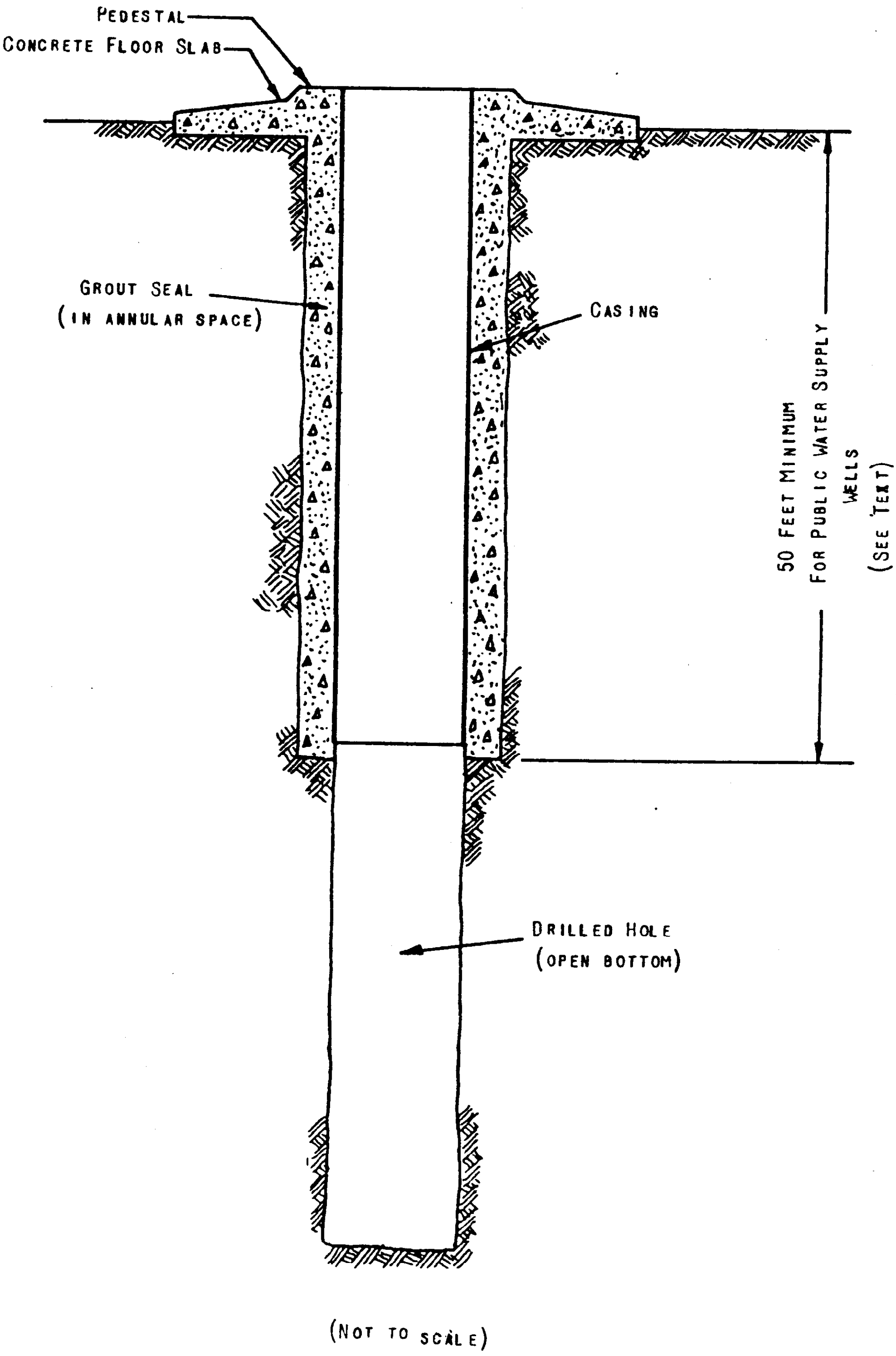
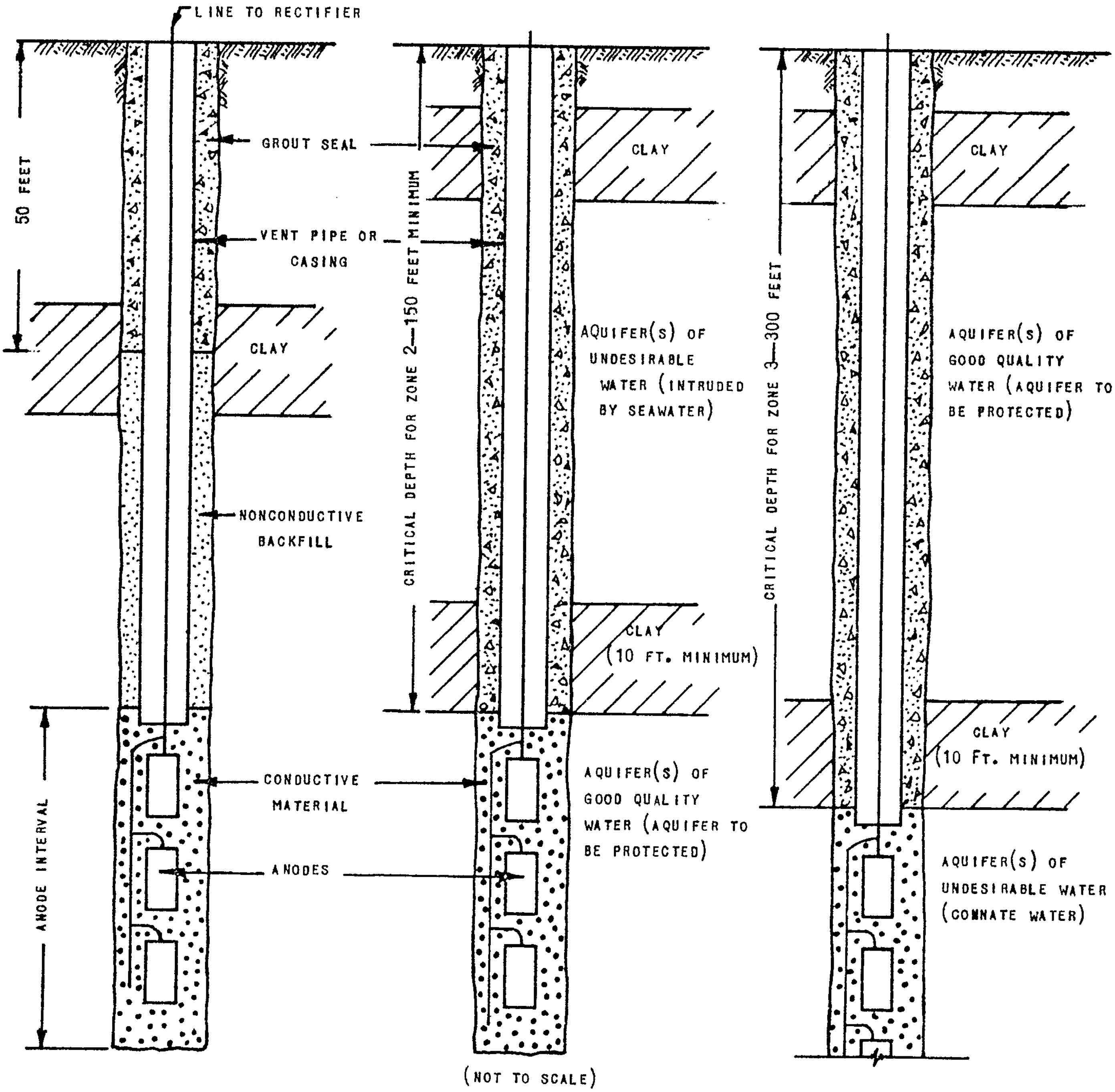


Figure 5. Example of Sealing Upper Annular Space
Well in Bedrock Formation


LINE TO RECTIFIER
50 FEET
GROUT SEAL
VENT PIPE OR CASING
CLAY
NONCONDUCTIVE BACKFILL
ANODE INTERVAL
CONDUCTIVE MATERIAL
ANODES
CRITICAL DEPTH FOR ZONE 2—150 FEET MINIMUM
CLAY
AQUIFER(S) OF UNDESIRABLE WATER (INTRUDED BY SEAWATER)
CLAY (10 FT. MINIMUM)
AQUIFER(S) OF GOOD QUALITY WATER (AQUIFER TO BE PROTECTED)
(NOT TO SCALE)
CRITICAL DEPTH FOR ZONE 3—300 FEET
CLAY
AQUIFER(S) OF GOOD QUALITY WATER (AQUIFER TO BE PROTECTED)
CLAY (10 FT. MINIMUM)
AQUIFER(S) OF UNDESIRABLE WATER (CONNATE WATER)

A. General requirement, Zone 1.

B. Sealing Requirement for Wells Deeper Than 150 Feet in Zone 2.

C. Sealing Requirement for wells deeper than 300 feet in Zone 3.

FIGURE 6. EXAMPLES OF SEALING CONDITIONS CATHODIC PROTECTION WELLS

APPENDIX C. GLOSSARY OF SELECTED TERMS

Alkalinity - The capacity of the solution to neutralize acid. In most natural water, the alkalinity is practically all produced by dissolved carbonate and bicarbonate ions and measured as concentrations of these.

Anion - A negatively charged ion.

Aquifer - Formations having structures that permit appreciable water to move through them under ordinary conditions.

Aquitard(or Aquiclude) - An impermeable formation which may contain water but is incapable of transmitting significant water quantities.

Artesian - Under pressure by confinement.

Artesian Well - A well tapping a confined or artesian aquifer in which the static water level stands above the top of aquifer.

Base Exchange(or Cation Exchange) - An adsorption-desorption process whereby cations held by minute electrical changes at the surface of fine grained formation particles are replaced or exchanged by other cations contained in the groundwater; the direction of the exchange is toward an equilibrium of the bases present in the water and on the fine materials in the aquifer.

Cation - A positively charged ion.

Concentration - The amount of a substance in weight, moles, or equivalents contained in unit volume.

Cone of Depression - A conic shaped groundwater drawdown surface or piezometric surface that is induced below the static surface by a pumping well. The outer limit of the cone of depression defines the area of influence of well while pumping.

Confined Aquifer - An aquifer overlaid by material sufficiently impervious to retain groundwater in the aquifer under pressure.

Connate Water - Water which was entrapped in a geologic formation at the time the formation was deposited. If the formation was deposited in the ocean or a saline lake, the connate water is also saline.

Contamination - An impairment of the quality of water by microorganisms, chemicals, sewage, or industrial waste which renders the water unfit for its intended use. In California, this means the water constitutes an actual hazard to public health(see also Pollution).

Drawdown - The distance the water table or piezometric surface is temporarily lowered at a given point as a result of pumping of a well. The lowering occurs as a result of water removed from the aquifer or a lowered pressure response surrounding the well. After the cessation of pumping, the drawdown level normally rises to near its static level before pumping after a short period.

Equilibrium (Chemical) - A state of affairs in which a chemical reaction and its reverse reaction are taking place at equal velocities, so that the concentrations of reacting substances remain constant.

Equivalent Weight Per Litre - Unit of concentration which is expressed in reacting values or combining values whereby positively charged cations and negative anions combine and dissociate in definite weight ratios. The equivalent weight of an ion is the ratio of its atomic weight to its valence. For convenience, concentrations are reported in one-thousandths of a gram equivalent weight per litre of solution or simply milliequivalent per litre (me/l).

Flowing Artesian Well - A well in which water is lifted by hydrostatic pressure above the land surface at the well.

Geochemical Process - A chemical or mineralogical interaction of groundwater and the formation materials; such processes include, but are not limited to, base exchange, sulfate reduction, dissolution and precipitation, oxidation-reduction.

Gradient - The rate of change per unit of length, such as the slope of the land, stream channel, water surface, water table, or piezometric surface, or any other surface.

Groundwater - Subsurface water in saturated porous rocks and soils.

Groundwater Basin - A physiographic unit containing one large aquifer or several connected and interrelated aquifers. In practice, definition is general and loose, but implies an area containing a groundwater reservoir capable of furnishing a substantial water supply.

Hardness (of Water) - A measure of the calcium and magnesium content and is customarily expressed as the equivalent of calcium carbonate. Classification of water as based upon hardness is as follows:

Soft	0-60 mg/l as $CaCO_3$
Moderately Hard	61-120 mg/l as $CaCO_3$
Hard	121-180 mg/l as $CaCO_3$
Very Hard	More than 180 mg/l as $CaCO_3$

Injection Well - A well used to admit water from the surface to underground formations; includes recharge well, waste disposal well, etc.

Isochlor Lines - Lines of equal cholride concentration as interpreted on a map, based upon groundwater sampling and analyses. The interpretive map constitutes an isochlor map of the groudwater.

Leakance - A measure of the ability of water to move through a confining bed and is defined as the rate of flow per unit of time per unit of an interfacing area per head difference across the confining bed.

Milliequivalent per litre (me/l) - one thousandth of a gram equivalent weight per litre of solution. Refer to Equivalent Weight Per Litre.

Overdraft - The condition in a groundwater basin where the amount of water withdrawn by pumping exceeds the amount of water replenishing the basin over a long time period.

Perched Groundwater - Unconfined groundwater occurring in a saturated zone separated from the main body of groundwater by an unsaturated zone.

pH - Term used to express the intensity of the acid or alkaline condition of a solution.

Permeability - A measure of the ability of a material to convey water.

Piezometric Level (or Surface) - The level to which water will rise in a well that penetrates a confined aquifer.

Pollution - The addition of sewage, industrial wastes, or other harmful or objectionable material to water (See also Contamination).

Salinity - Of or pertaining to salt, salt content in soil or solution.

Saltwater Intrusion (or Seawater Intrusion) - Movement of salt water into freshwater aquifer. In coastal aquifers seawater intrusion occurs as a result of a reversal of the hydraulic gradient which is normally to the sea and reversed inland from the sea by increased pumping of the aquifer.

Semiperched Groundwater - Shallow groundwater overlying a body of groundwater from which it is not separated by an unsaturated alluvium (perched groundwater but not separated by an unsaturated zone from the main groundwater body; separation is achieved by the nearly impermeable nature of the perching clay layer and if the main groundwater body were drawn down, a true perching condition would result).

Specific Electrical Conductance (or EC - Electrical Conductivity) - Denotes relative salinity concentration or total dissolved solids by measuring the electrical conductivity of a solution at 25 degrees Celsius. Unit used in this report is micromhos per centimeter at 25 degrees Celsius (umho/cm); more recently the term used as metric equivalent is microsiemens per centimetre (uS/cm).

Subsidence (of Land Surface) - Lowering of the land surface that occurs when intensive groundwater pumping results in lowered water pressures in the groundwater basin materials. A similar type of subsidence can also result from oil field pressure reduction.

Sulfate Reduction - A geochemical process which results in bacterial reduction of sulfate ion to hydrogen sulfide along with concomitant oxidation of some of the organic matter to carbon dioxide, which in turn increases the bicarbonate content of the water (increases in alkalinity).

Total Dissolved Solids (TDS) - The amount of organic and inorganic matter (by weight) dissolved in a given quantity of water. It is usually stated in milligrams per liter (mg/l). Classification of water as based upon total dissolved solids are a follows:

Fresh	0-1,000 mg/l TDS
Brackish	1,000-10,000 mg/l TDS
Salty	10,000-100,000 mg/l TDS
Brine	More than 100,000 mg/l TDS

Unconfined Aquifer - An aquifer that occurs under water table conditions, that is the water level is below the bottom of any upper confining bed.

Water Quality - The chemical, physical, and biological properties of water which affects its suitability for use.

Water Table - The surface of an unconfined groundwater body at which the pressure is atmospheric (not under pressure).

APPENDIX D

ENGLISH - METRIC EQUIVALENTS

Each unit with its abbreviation is followed by its equivalent in one or other units of the same quantity.

Length	Inch (in) - 2.54 centimtre (cm) Centimetre (cm) - 0.3937 inch (in) Foot (ft) - 0.3048 metre (m) Metre (m) - 3.2808 feet (ft); 37.37 inches (in) Mile (mi) - 1.6094 kilometre (km) Kilometre (km) - 0.6214 mile (mi)
Area	Acre (a) - 43,560 square feet (ft^2); 0.4047 hectare (ha) Hectare (ha) - 10,000 square metres (m^2); 2.471 acres (a) Square mile (mi^2) - 640 acres (a); 259 hectares (ha); 2.59 square kilometres (km^2) Square kilometre (km^2) - 100 hectares (ha); 0.384 square mile (mi^2)
Volume	Gallon (gal) - 3.7853 litres (l); 0.00378 cubic metre (m^3) Litre (l) - 0.2642 gallon (gal); 1.057 quarts (qt) Cubic metre (m^3) - 264.173 gallons (gal); 1,000 litres (l)
Groundwater storage	Acre-foot (ac-ft) - 1,233.5 cubic metres (m^3) Thousand acre-ft (ac-ft) - 1,233.500 cubic metres (m^3) 1.23 cubic hectometres (hm^3) Cubic hectometre(hm^3) - Million cubic metres (m^3); 810.71 acre-feet (ac-ft)
Concentration	Milligrams per litre (mg/l) - 1 part per million (ppm) Microgram per litre (ug/l) - 0.001 milligram per litre (mg/l), 0.001 part per million (ppm)

APPENDIX E

WELL NUMBERING SYSTEM

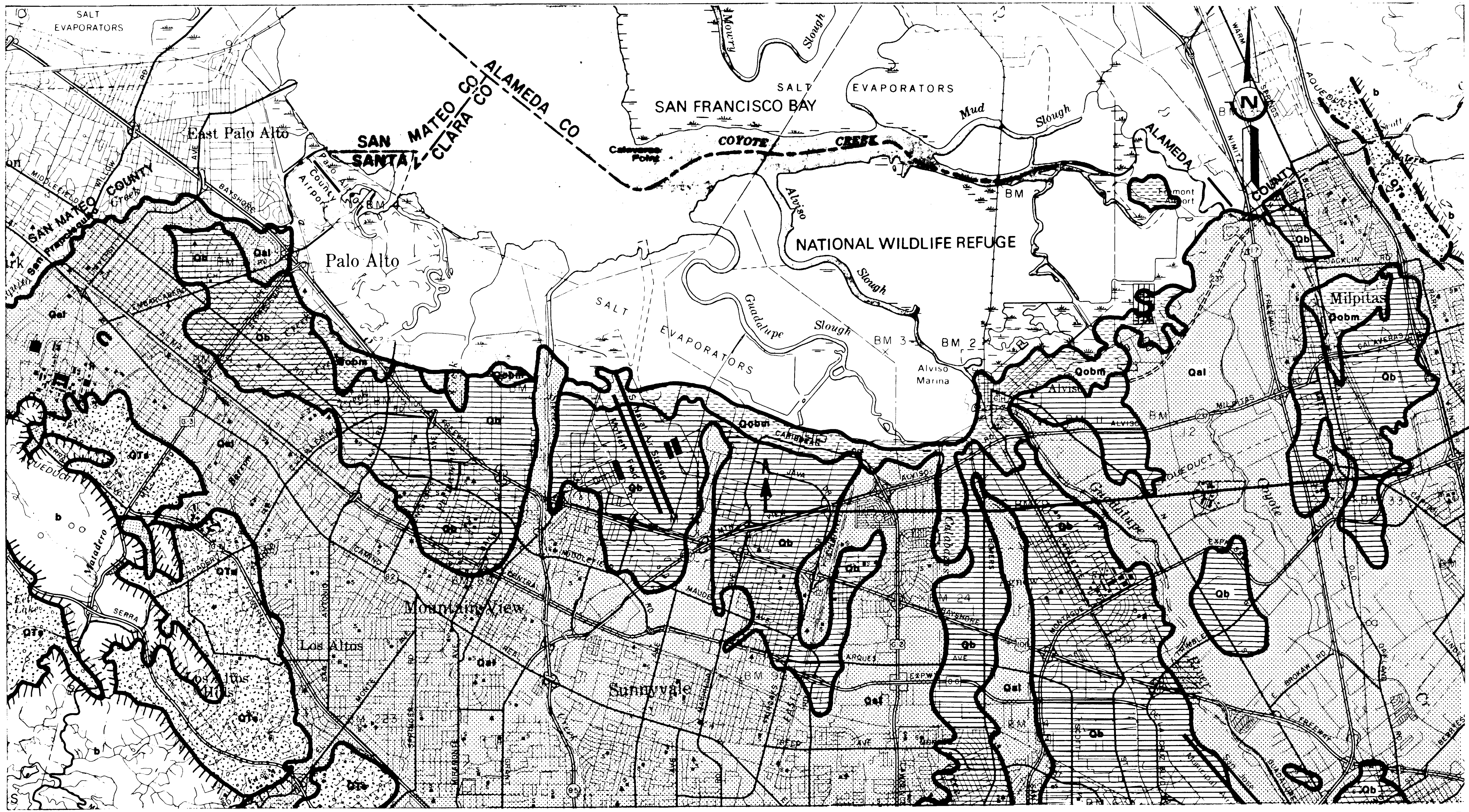
The well numbering system used in this report is the numbering system used by the United States Geological Survey and which denotes an approximate location. It is based on township, range, and section subdivisions of the Federal Land Survey, and conforms to that used in all groundwater investigations of the U.S. Geological Survey in California and the State Department of Water Resources.

Under this system, each section is divided into sixteen 40-acre tracts, which are lettered as follows:

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Wells are numbered within each of these 40-acre tracts according to the order in which they are located. For example, a well having the number 06S01W27H02 would be in Township 6 South, Range 1 West, Section 27, and would be further identified as the 2nd well located in the 40-acre tract "H". Township and range in Santa Clara County are for the Mount Diablo Base and Meridian.

PLATE 1



LEGEND

Unconsolidated, Water-bearing	Qb	Interfluvial Basin Deposits
	Qal	Alluvial Fan Deposits Include both young and old deposits
	Qobm	Older San Francisco Bay Mud
	QTs	Santa Clara Formation Compacted to lightly consolidated
Consolidated, Nonwater-bearing	b	Undifferntiated Bedrock Units
	A A'	Location of Geologic Section (Plate 3)

Notes:

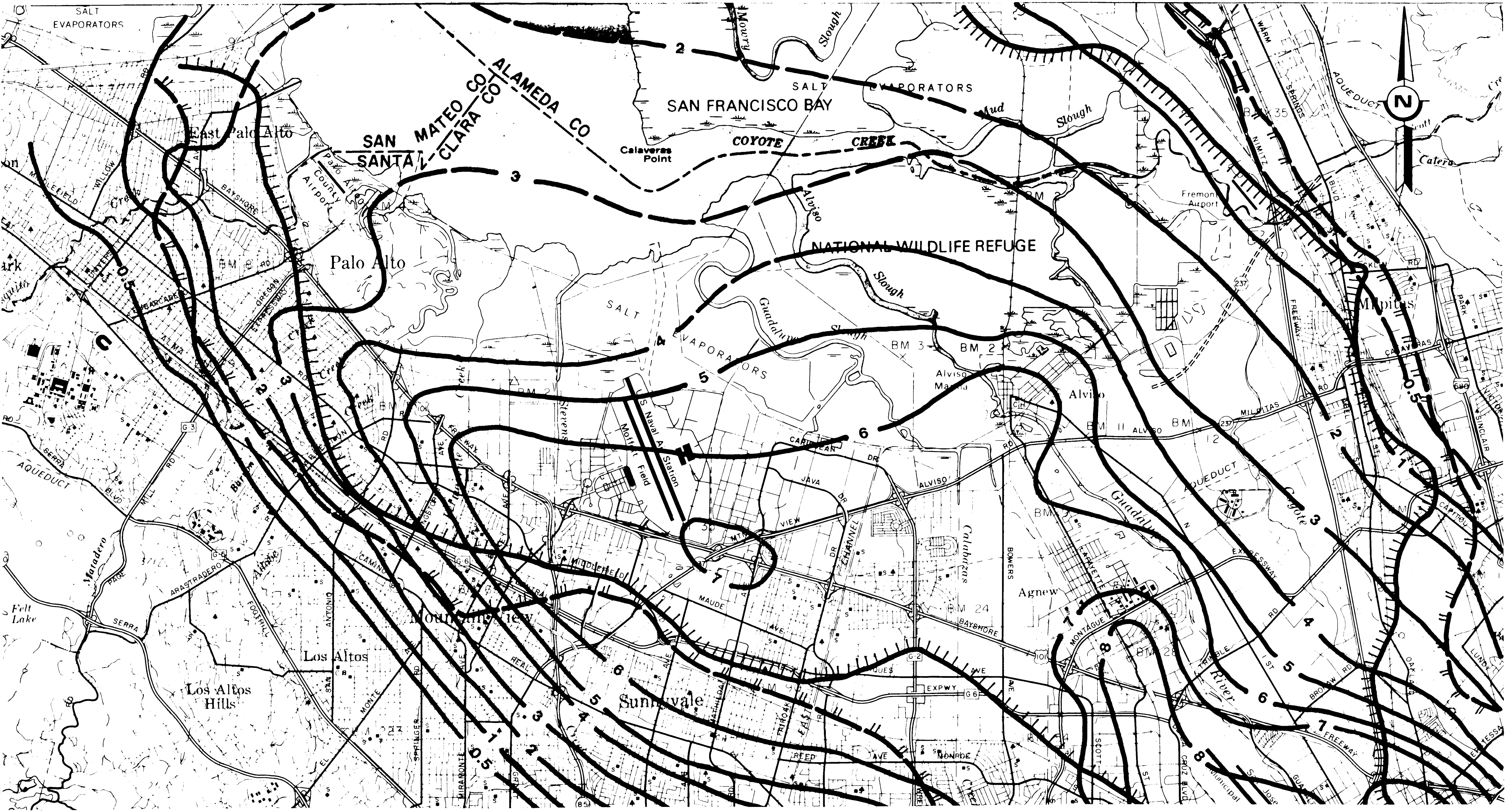
1. **Geology modified largely from E.J. HELLY and E.E. BRABB,1971,U.S. Geol. Survey**
2. **Refer to Plate 3 for Section A - A**

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

GENERAL LOCATION AND REGIONAL GEOLOGIC MAP

SEPTEMBER 1980
SCALE : 1"=5,000 ft.

PLATE 2



LEGEND

3 (In ft.) Line of equal land subsidence that had occurred from 1934 to 1967. Total subsidence which includes additional subsidence before and after the period between 1934 and 1967 would aggregate to a greater amount than indicated on this map. Dashed where poorly controlled. Units in feet.

Data are from J.F. Poland and R.L. Ireland, March 1969, U.S. Geological Survey, Sacramento, California.

Area of flowing artesian wells of the lower confined aquifer Circa 1920. Boundary is approximate.

Area of flowing artesian wells of the lower confined aquifer prior to 1920. Boundary is approximate.

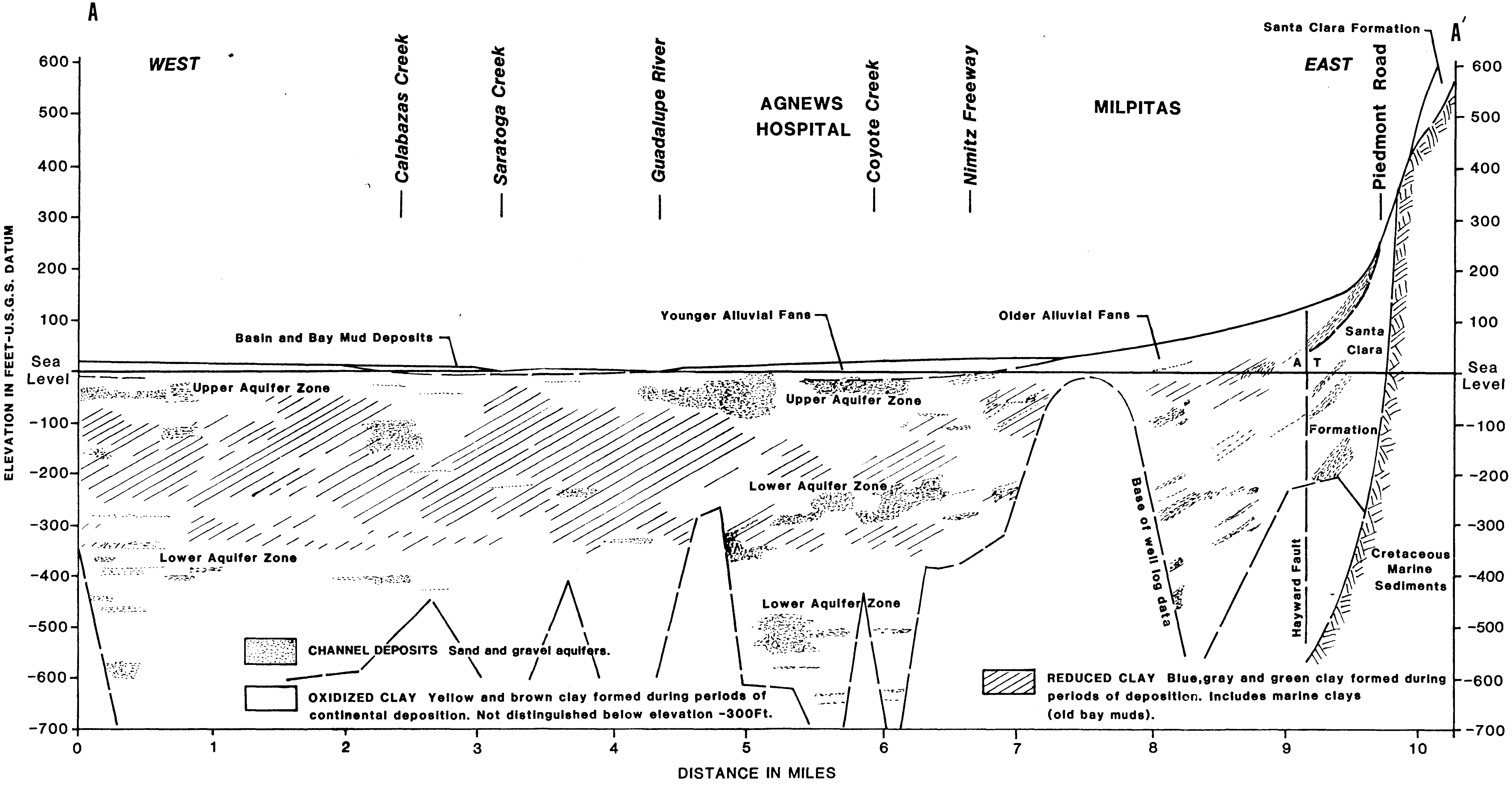
Data of flowing artesian wells from William O. Clark, 1924, U.S. Geological Survey.

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

LAND SUBSIDENCE AND HISTORIC FLOWING ARTESIAN WELLS MAP

SEPTEMBER 1980
SCALE : 1"=5,000 ft.

PLATE 3



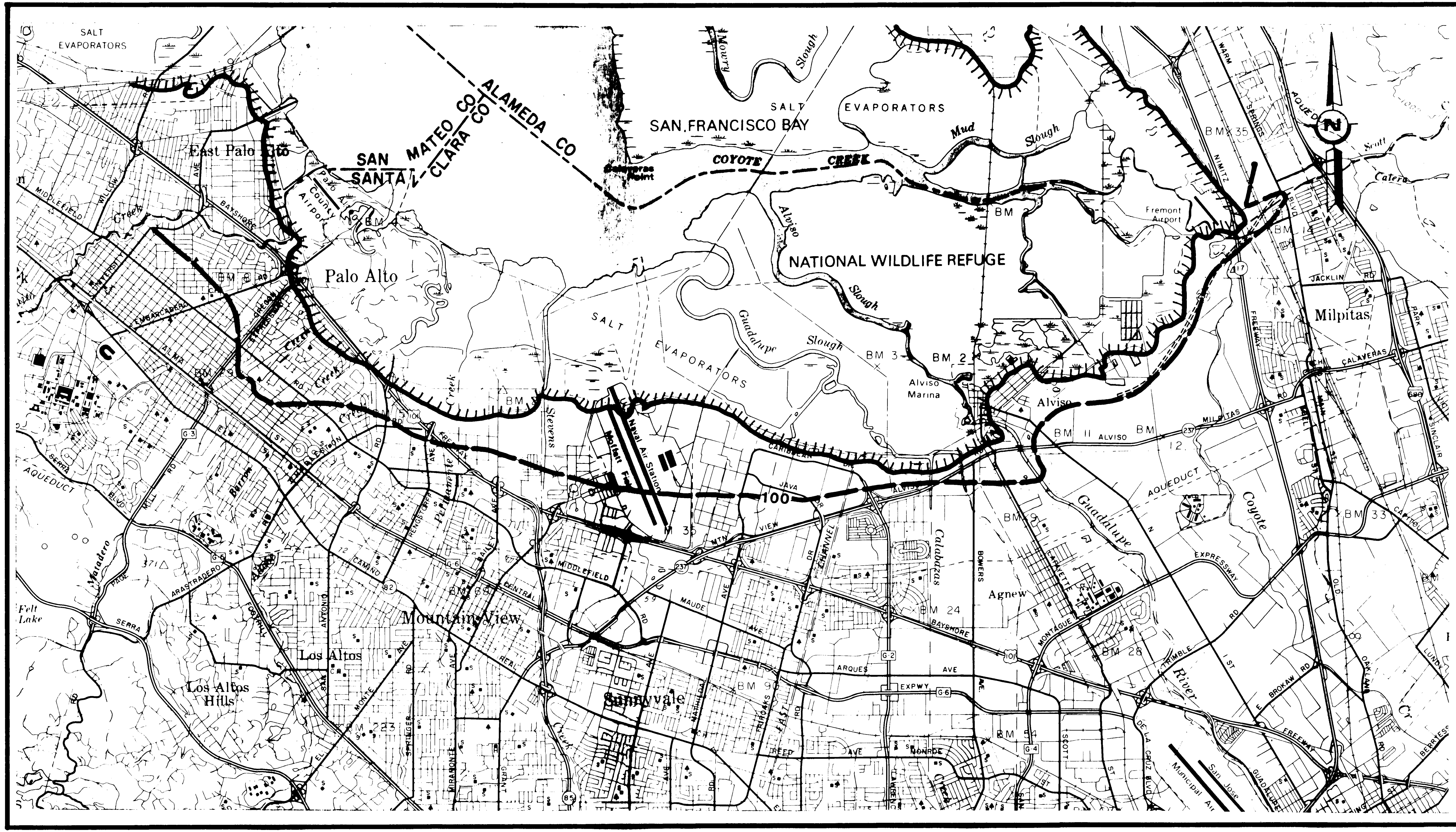
NOTES

1. Largely from California State Department of Water Resources, December 1975, Bulletin No. 118-1, Volume 3.
2. Refer to Plate 1 for location of section.

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

GEOLOGIC SECTION A - A', SOUTH OF ALVISO

SEPTEMBER 1980



LEGEND

Area of saltwater intrusion in the upper aquifer zone circa 1940. Boundary is approximate and delimited by the 100 milligrams per liter chloride content line. Data from C.F. TOLMAN and J.F. POLAND, 1940.

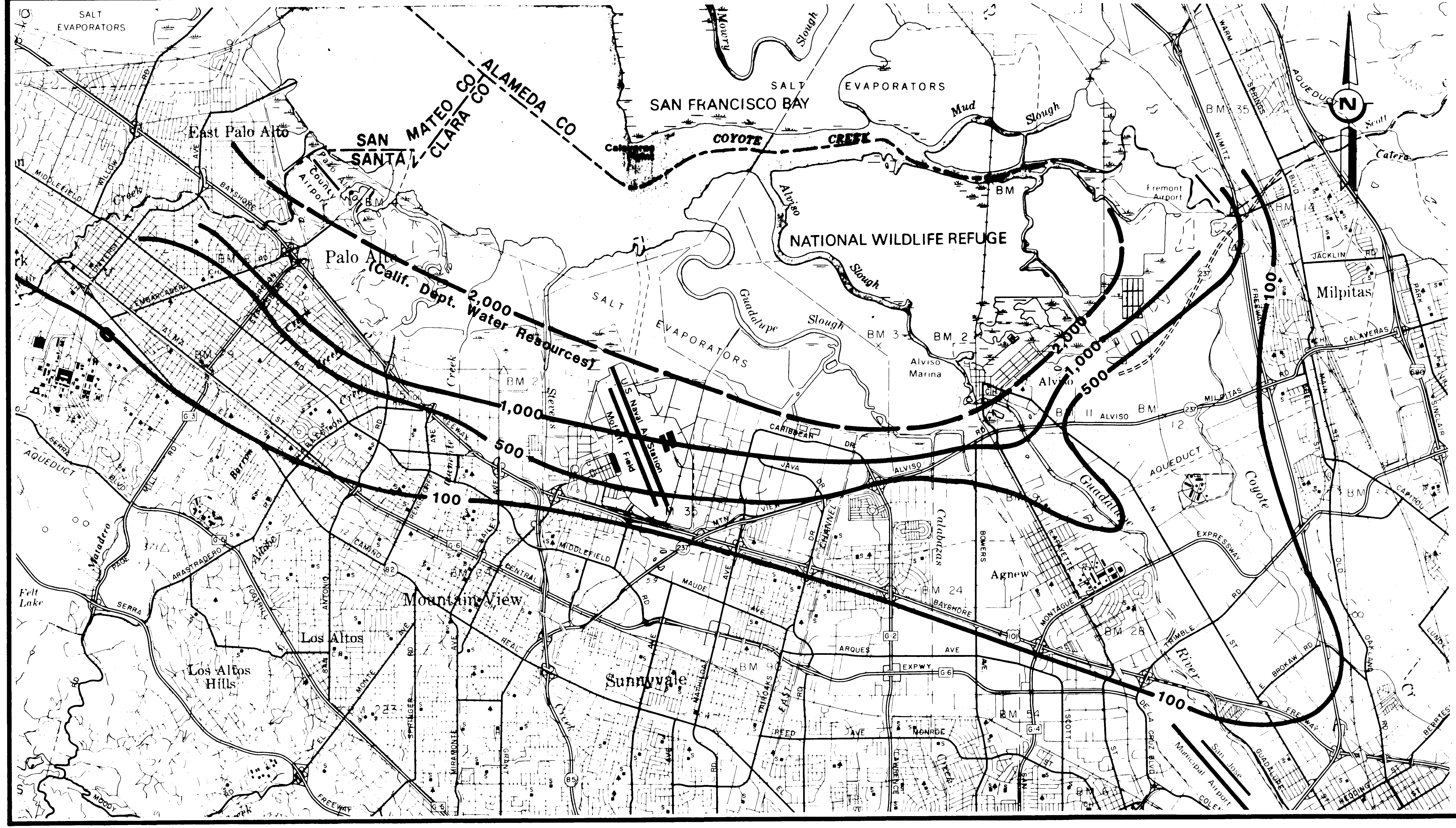
Area of historic marshlands of South San Francisco Bay, extending to shore of the Bay. Data from DONALD R. NICOLS and NANCY A. WRIGHT, 1971, U.S. Geol. Survey.

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

SALTWATER INTRUSION CONDITIONS CIRCA 1940 , UPPER AQUIFER ZONE

SEPTEMBER 1980
SCALE : 1" = 5,000 ft.

PLATE 5



LEGEND

100 Lines of equal chloride content in milligrams per liter. These lines delineate areas within which upper aquifer zone waters have been observed to contain the indicated chloride concentration at some time. Areas are generalized and all wells encompassed may not conform.

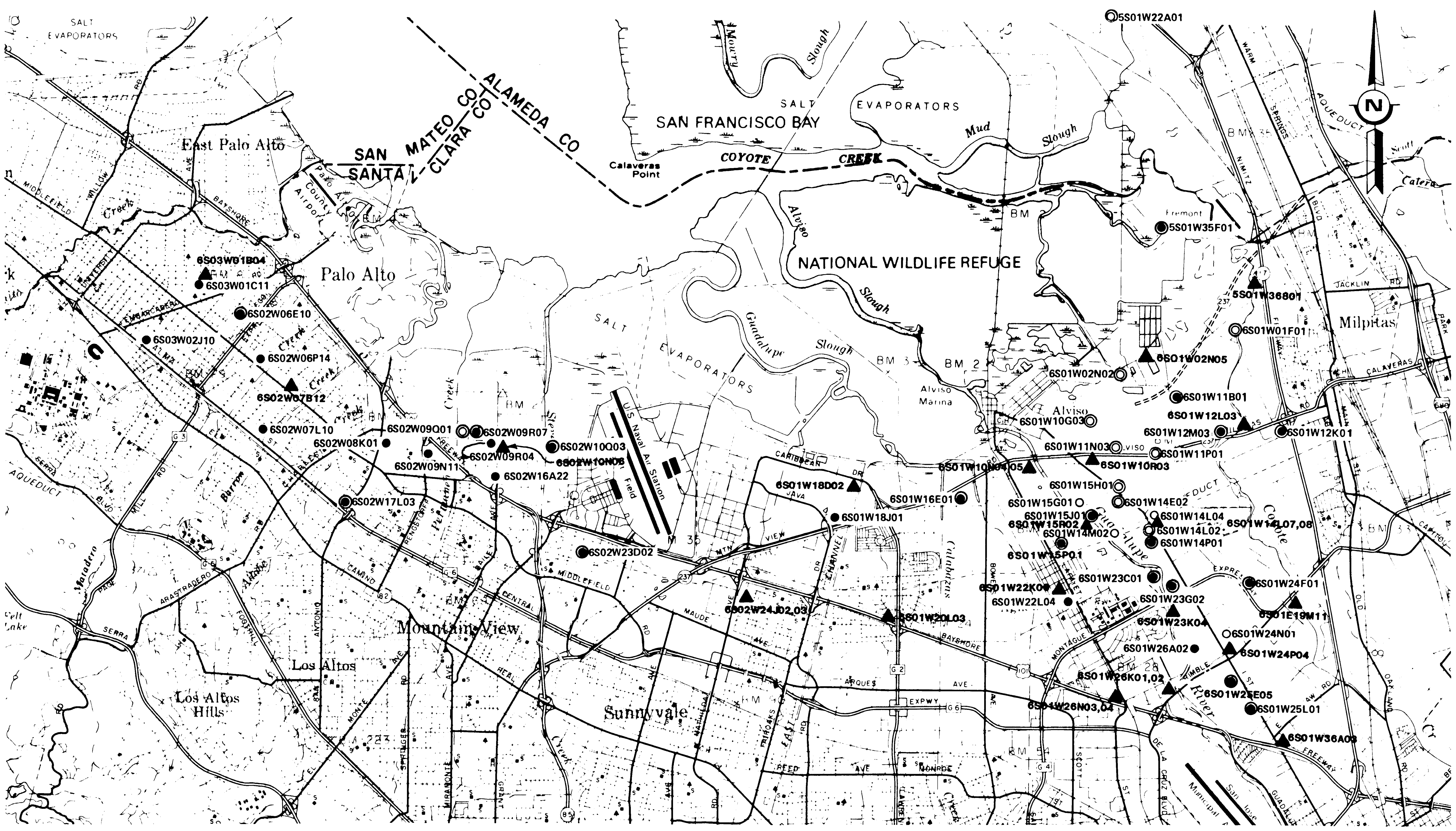
Map is from Arthur J. Inerfield and William C. Ellis, Sept. 1975

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

ISOCHLOR MAP DEPICTING CONDITIONS OF MAXIMUM INTRUSION AT SOME TIME AREALLY UPPER AQUIFER ZONE

SEPTEMBER 1980

SCALE : 1" = 5,000 ft.



LEGEND

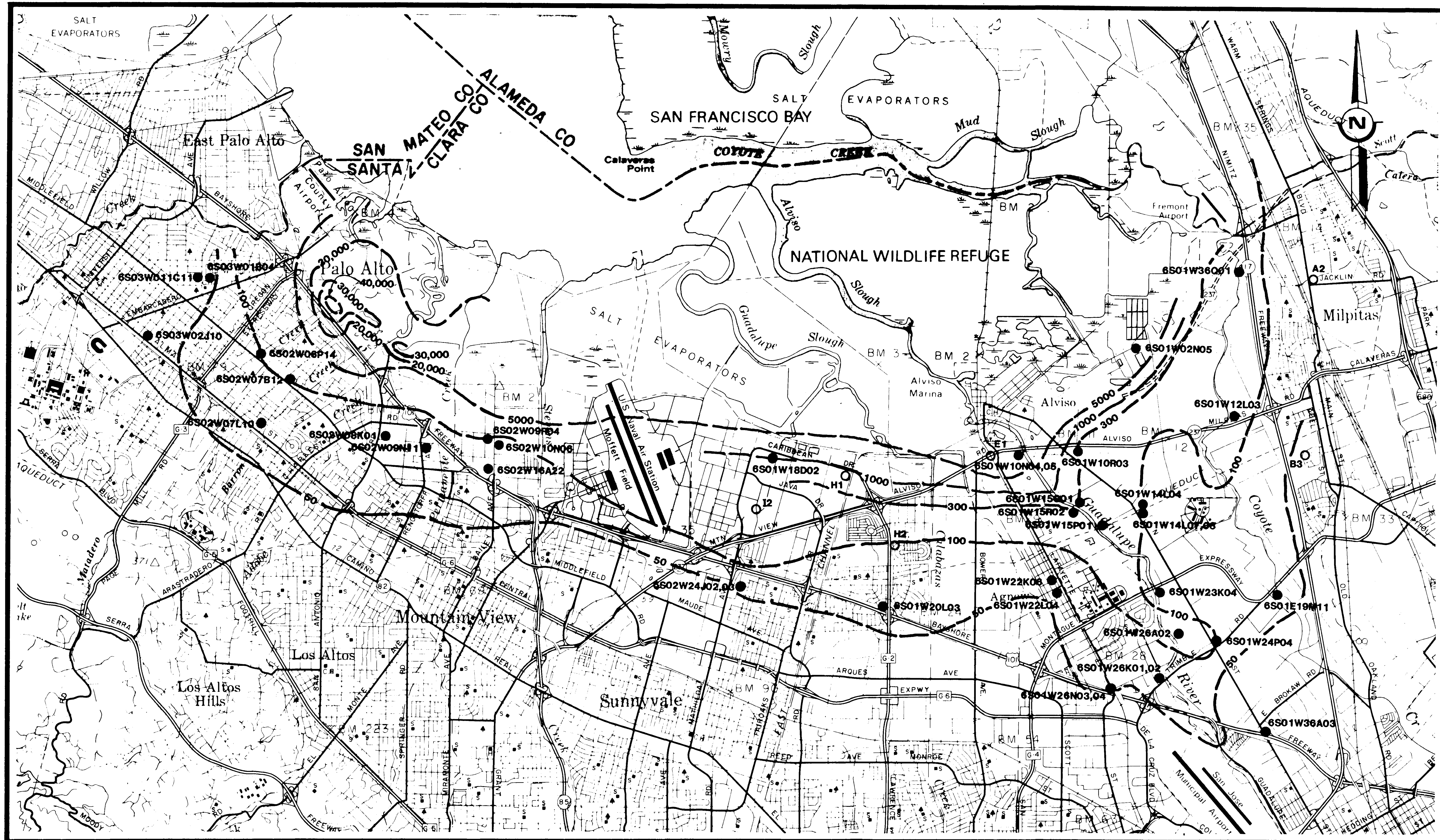
6S02W23D02		Well number
Well less than or suspected to be less than 100 feet in depth. Monitors upper confined zone and/or semiperched zone.	●	Salinity monitoring program well.
	○	Salinity and depth to water monitoring program well.
	▲	Salinity monitoring program well installed Spring 1977 and July 1978. Known perforated intervals.
Well deeper than or suspected to be deeper than 100 feet. Monitors lower confined zone or may be compositely perforated in both upper and lower zones.	◉	Salinity monitoring program well.
	◎	Salinity and depth to water monitoring program well.

NOTE: Refer to Tables 3 and 5 for tabulation of well construction data.

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

SALINITY MONITORING WELLS
SANTA CLARA COUNTY BAYLANDS

SEPTEMBER 1980
SCALE : 1" = 5,000 ft.



LEGEND

▬ ▬ 100 ▬ ▬ Lines of equal chloride content in milligrams per liter, largely for conditions 1972 to 1978. Sources of data include samples and analyses from current salinity monitoring program wells (Plate 6) plus other data from various special study wells. Where numerous repetitive values for a data point were available, the overall prevailing values during the period 1972-74 were used.

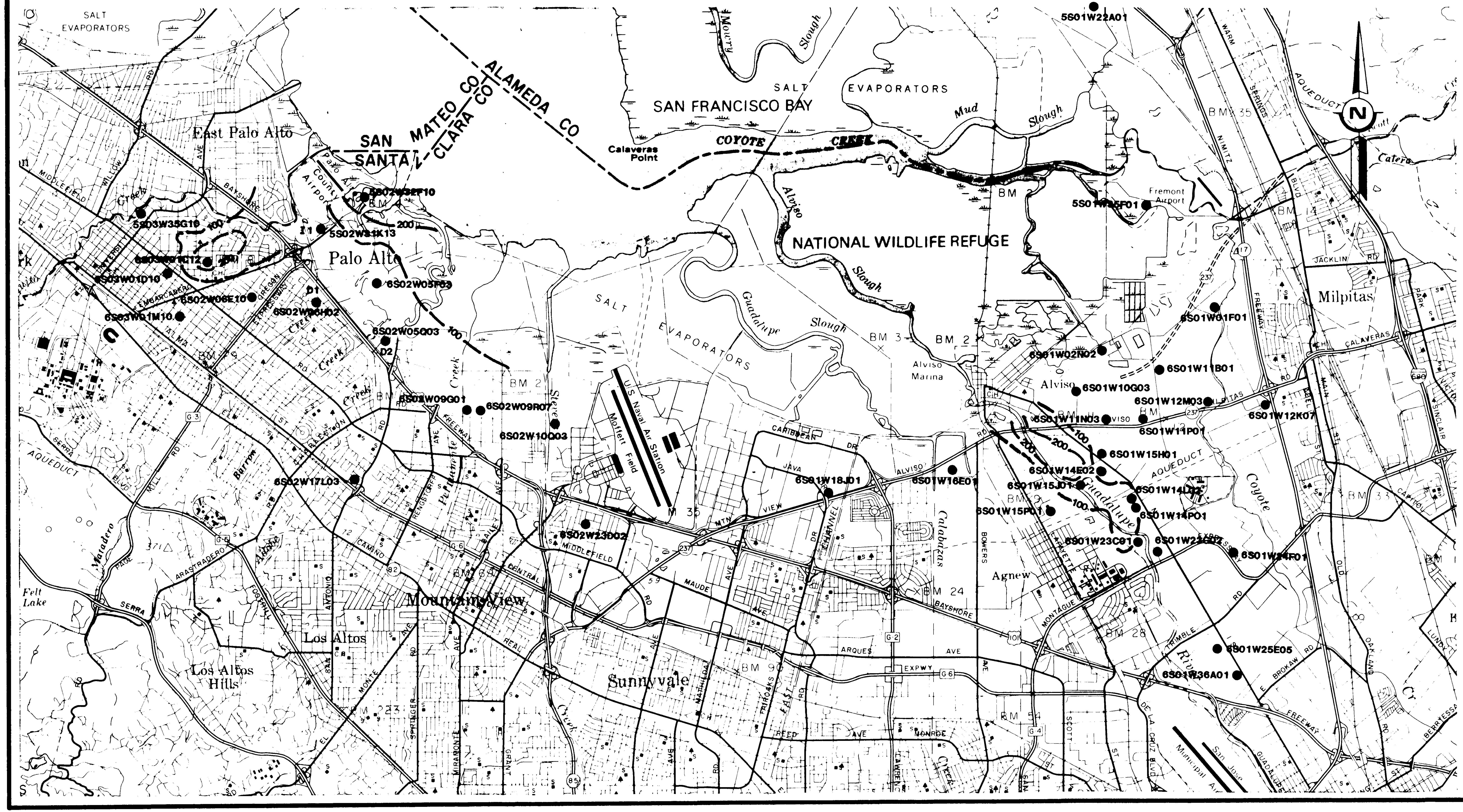
● 6S01W15R02 Salinity monitoring program wells less than 100 feet in depth.

○ B2 Location of test holes less than 100 feet in depth.

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

PRESENT CONDITIONS ISOCHLOR MAP OF UPPER AQUIFER ZONE

SEPTEMBER 1980
SCALE : 1"=5,000 ft.



LEGEND

—— 100 —— Lines of equal chloride content in milligrams per liter. Largely for conditions 1972 to 1978. Sources of data from current salinity monitoring program wells (Plate 6) plusdata from various special study wells. Where numerous repetitive values for a data point were available, the prevailing values were used. In the 1960's the values were higher and the areal extent of contamination was greater. Contamination of this lower zone is occuring vertically from the upper zone and hence patterns of lower zone of contamination are spotty.

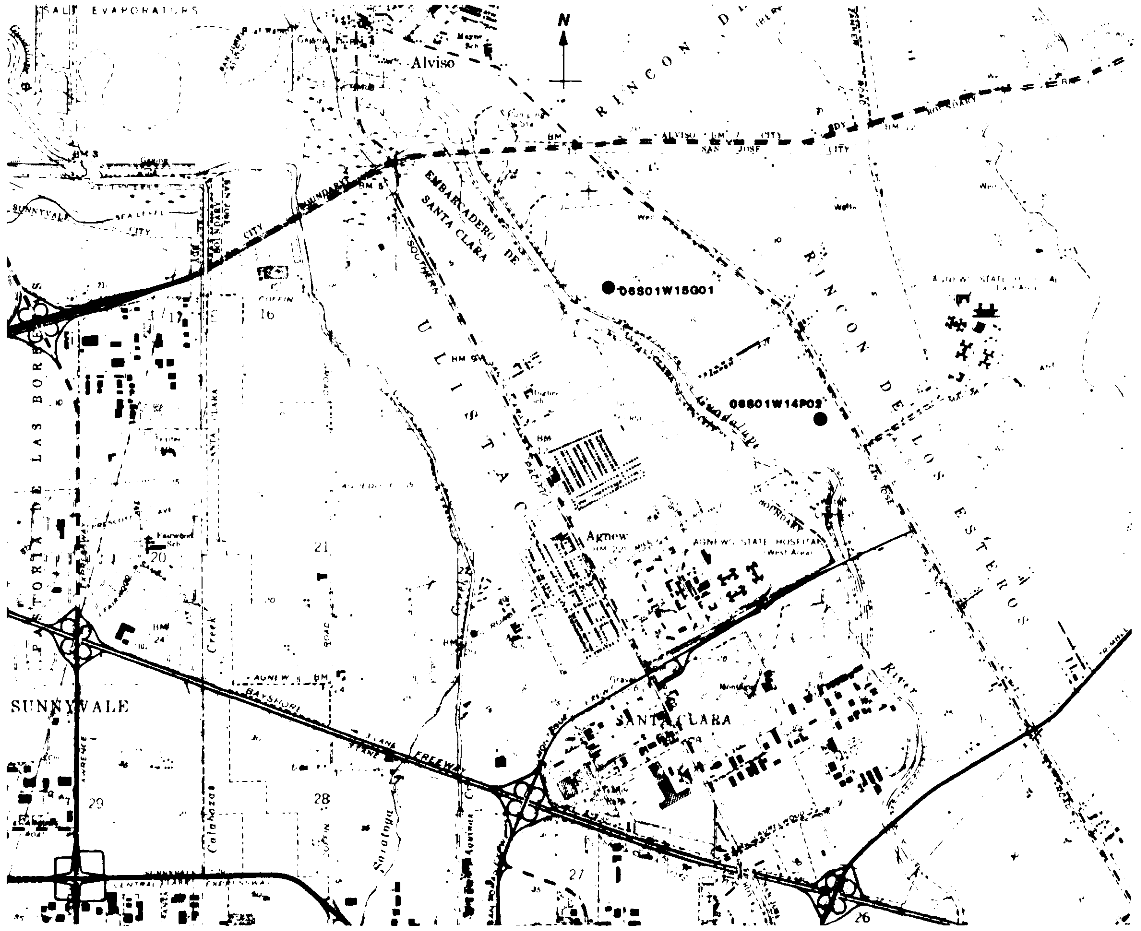
● 6S01W15H01 Salinity monitoring program wells deeper or suspected to be deeper than 100 feet. Several other deep wells included.

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

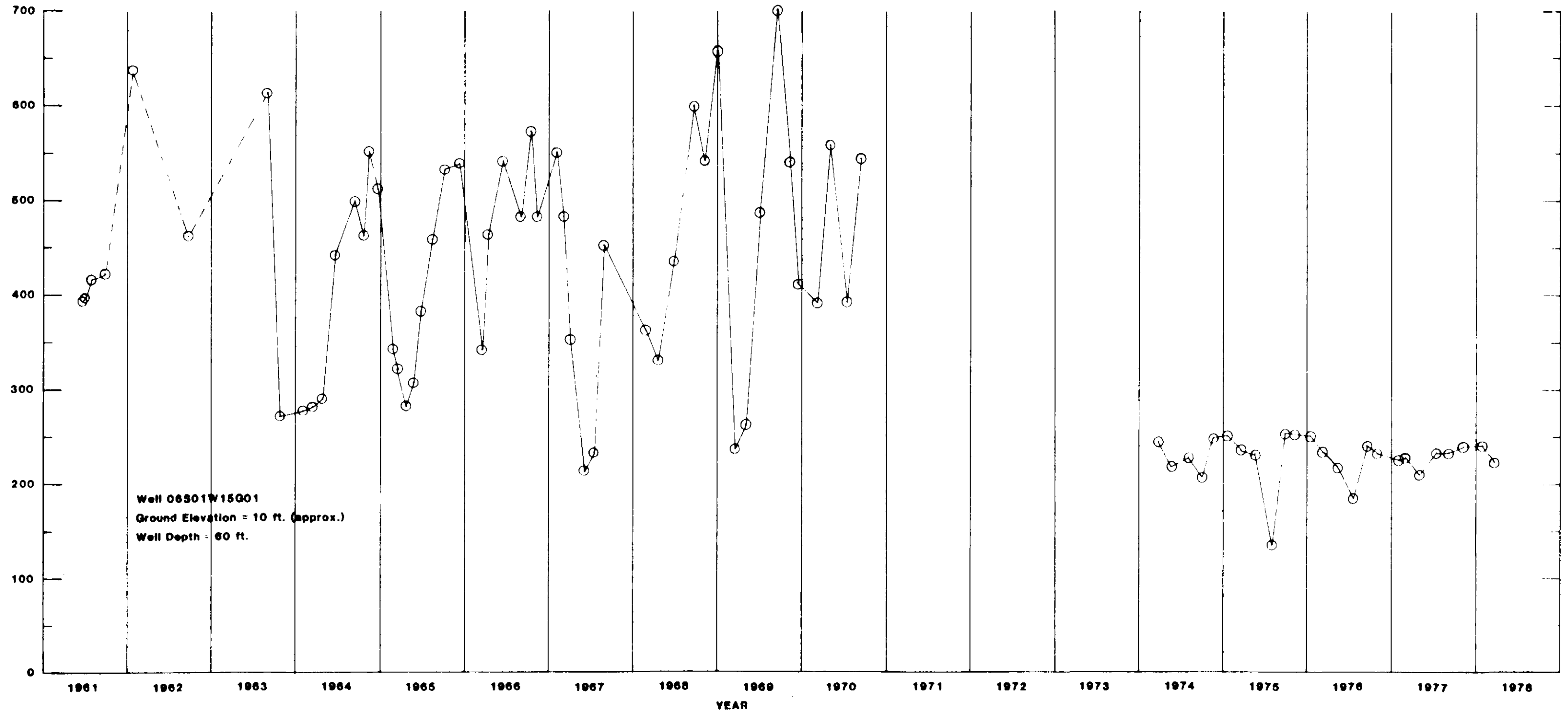
PRESENT CONDITIONS ISOCHLOR MAP OF LOWER AQUIFER ZONE

SEPTEMBER 1980
SCALE : 1" = 5,000 ft.

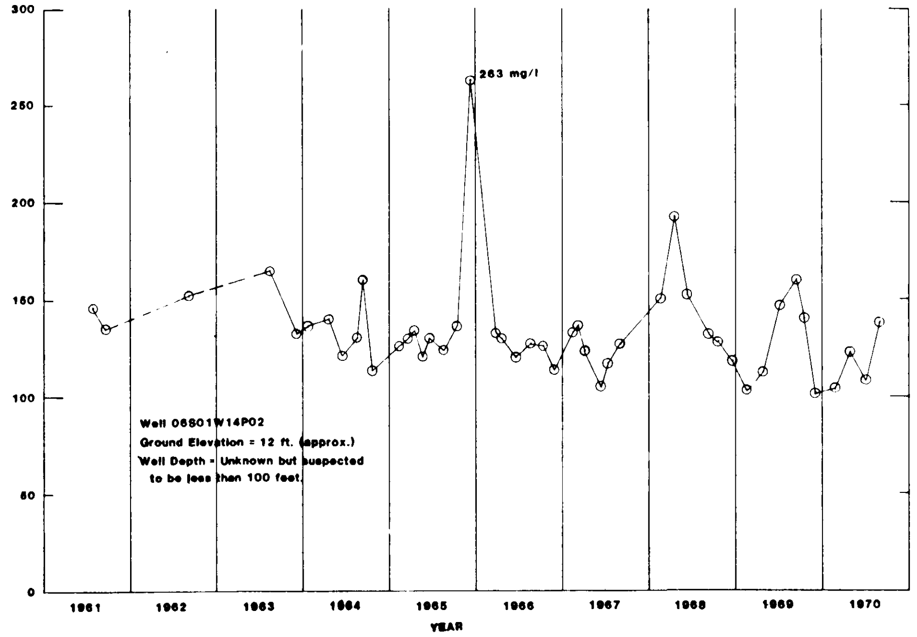
PLATE 9



WELL LOCATION



Well 06S01W15G01
Ground Elevation = 10 ft. (approx.)
Well Depth = 60 ft.



Well 06S01W14P02
Ground Elevation = 12 ft. (approx.)
Well Depth = Unknown but suspected
to be less than 100 feet.

REV	DESCRIPTION	DATE	APPR

REFERENCE INFORMATION AND NOTES

1. Represents selected examples ; limited by data availability.
2. Ground elevation at wells was approximated off U.S.G.S. 7.5' quadrangle map and was not corrected for subsidence.
3. Water level in 0 to 100 foot zone occurs in baylands at shallow depths and is subject to only minor variations.

DATE
DESIGN
DRAWN
CHECKED

Santa Clara Valley Water District

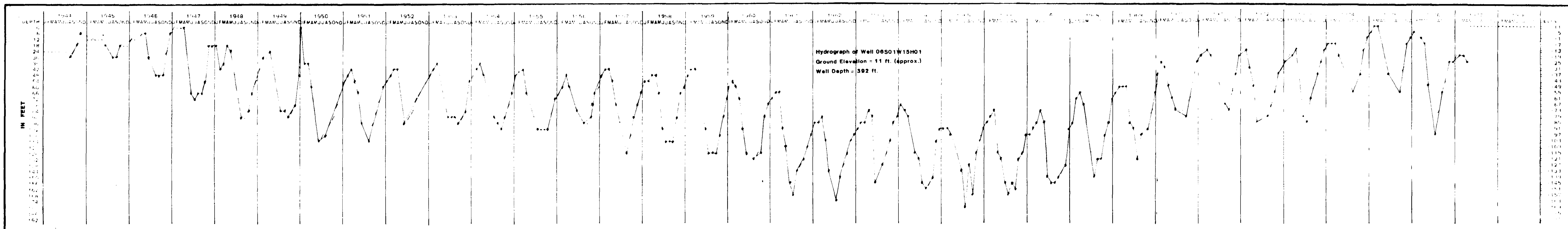
ENGINEERING CERTIFICATION
PROJECT ENGINEER R.C.E. NO. 22948

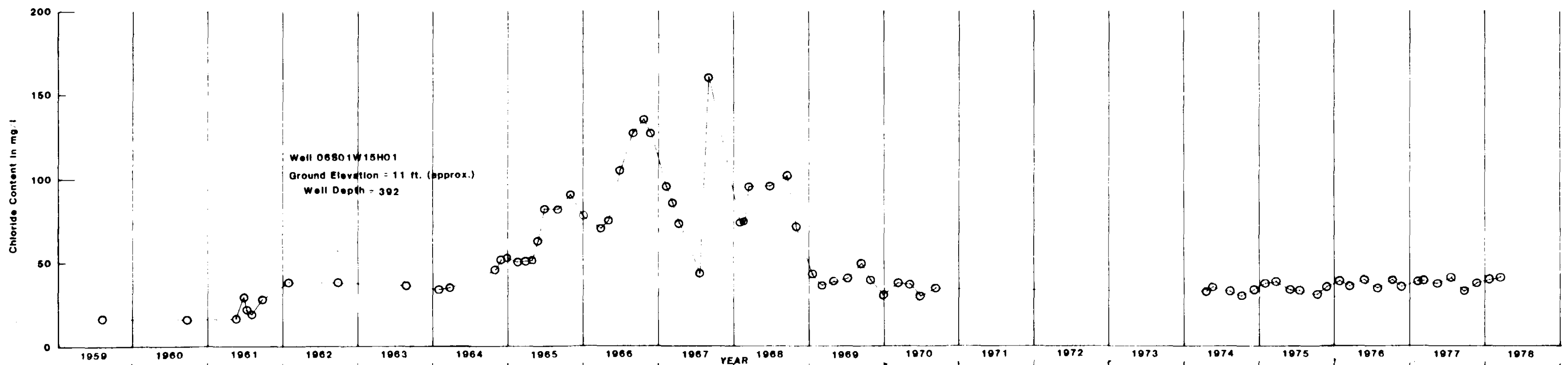
ENGINEERING APPROVAL
DIVISION ENGINEER R.C.E. NO.

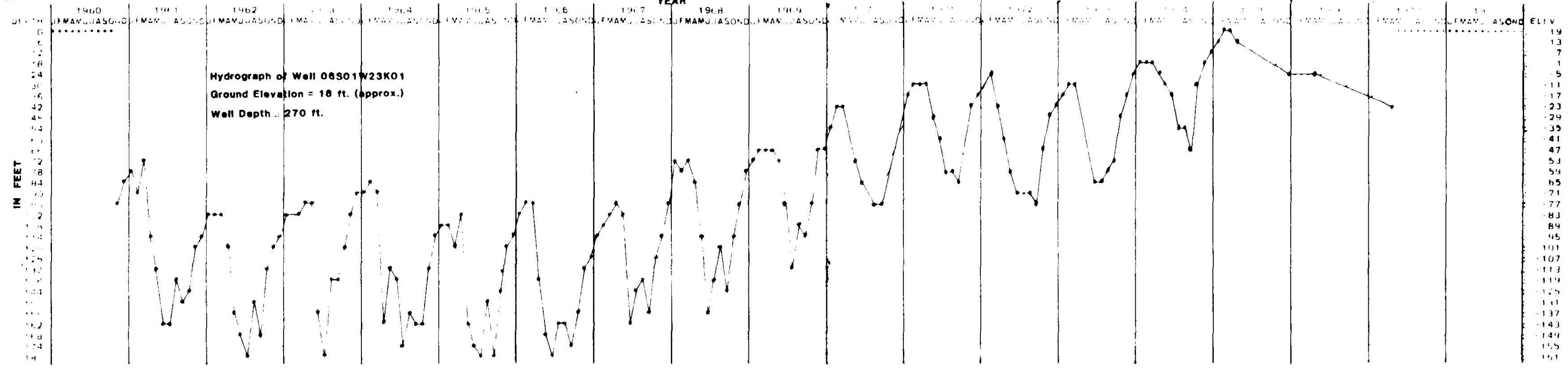
SALTWATER INTRUSION INVESTIGATION
SELECTED EXAMPLES OF TIME / CHLORIDE-CONTENT PLOTS,
UPPER AQUIFER ZONE ,ALVISO AREA
SEPTEMBER 1980

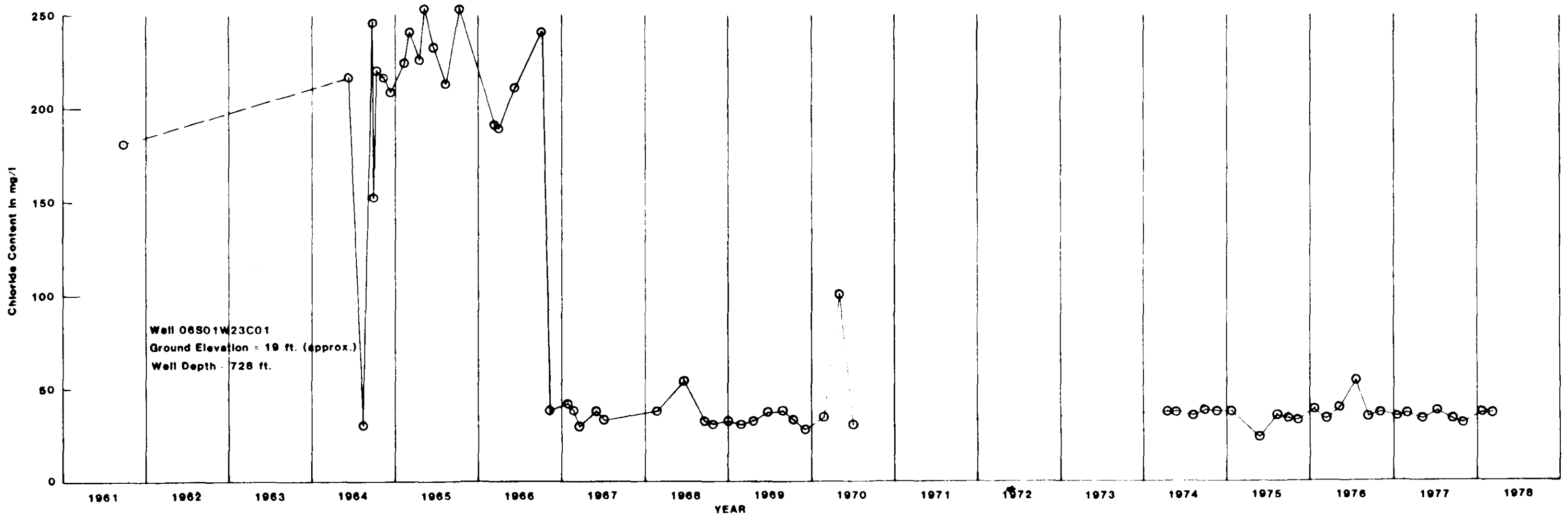
SCALE
SHEET

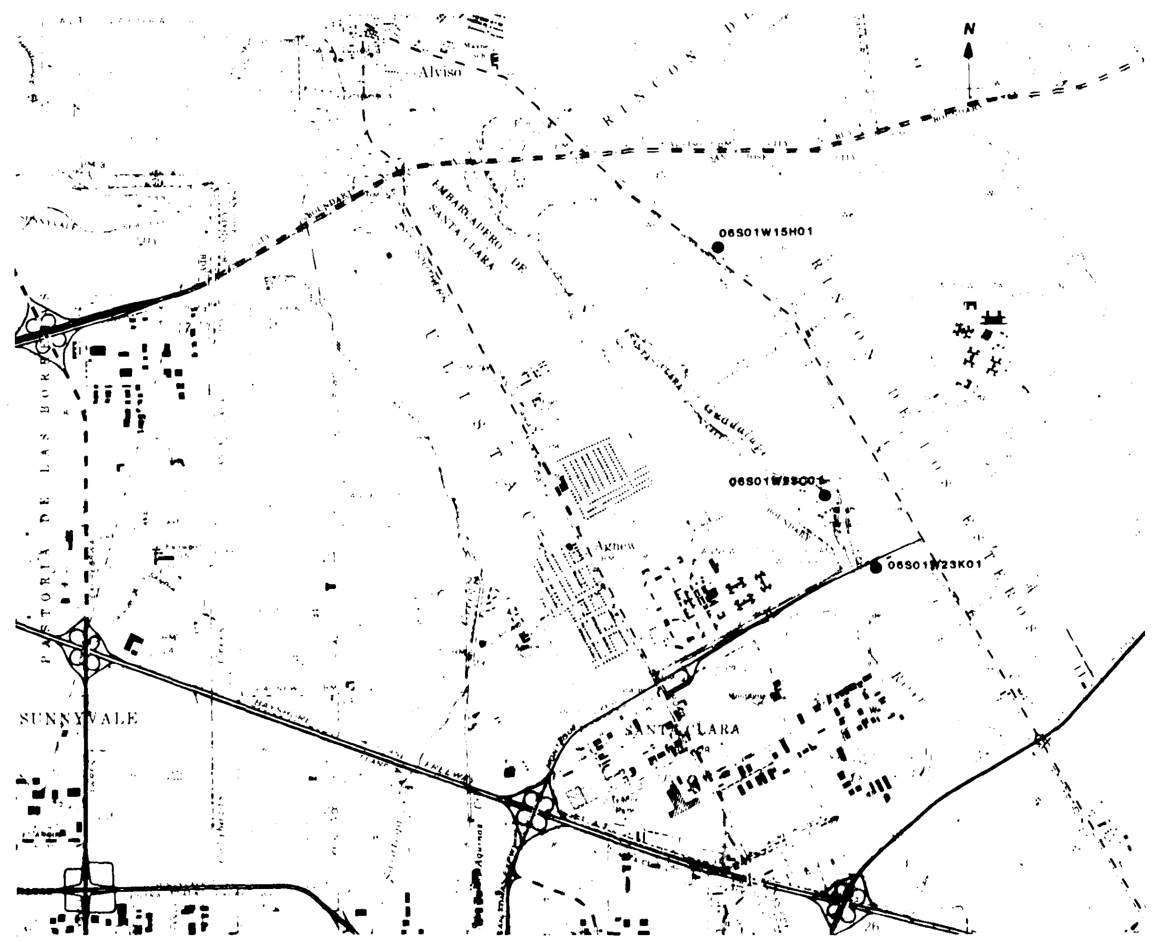
PLATE 10











WELL LOCATION

2,000 1,000 0 2,000

Scale of Feet

REV	DESCRIPTION	DATE	APPR

REFERENCE INFORMATION AND NOTES

1. Represents selected samples ; limited by data availability.
2. Hydrograph for Well 06S01W23C01 was not available so hydrograph of nearby Well 06S01W23K01 was used in the correlation.
3. Ground elevation at wells was approximated off U.S.G.S. 7.5' quadrangle map and was not corrected for land subsidence.

DATE

DESIGN

DRAWN

CHECKED

Santa Clara Valley Water District

SALTWATER INTRUSION INVESTIGATION

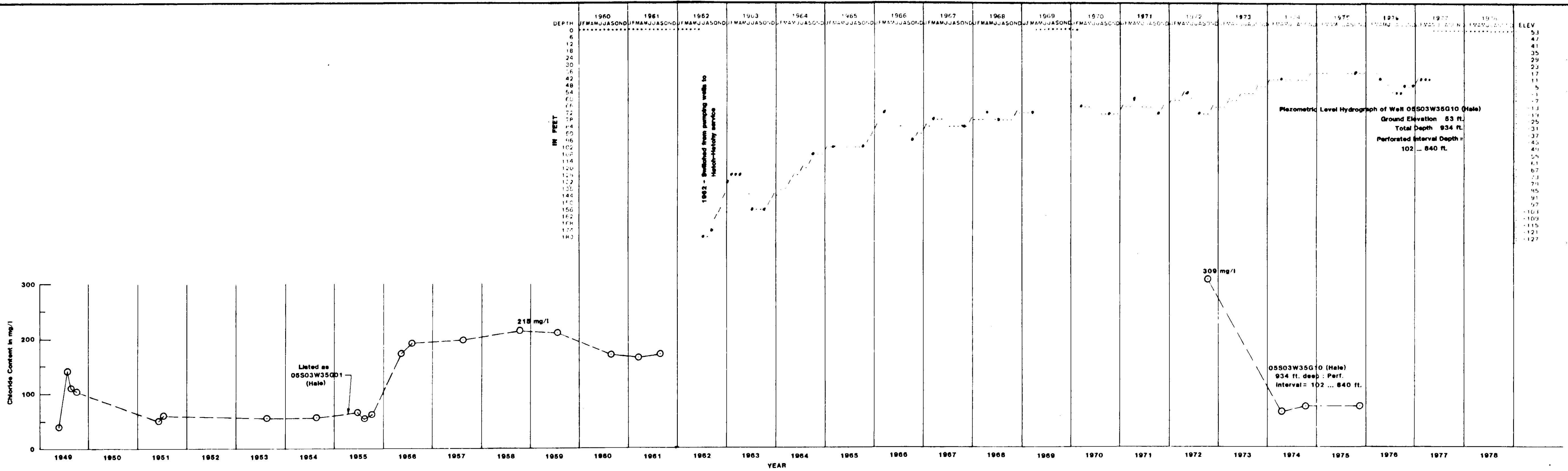
SELECTED EXAMPLES OF TIME / CHLORIDE-CONTENT PLOTS AND WELL HYDROGRAPH PLOTS , LOWER AQUIFER ZONE ALVISO AREA

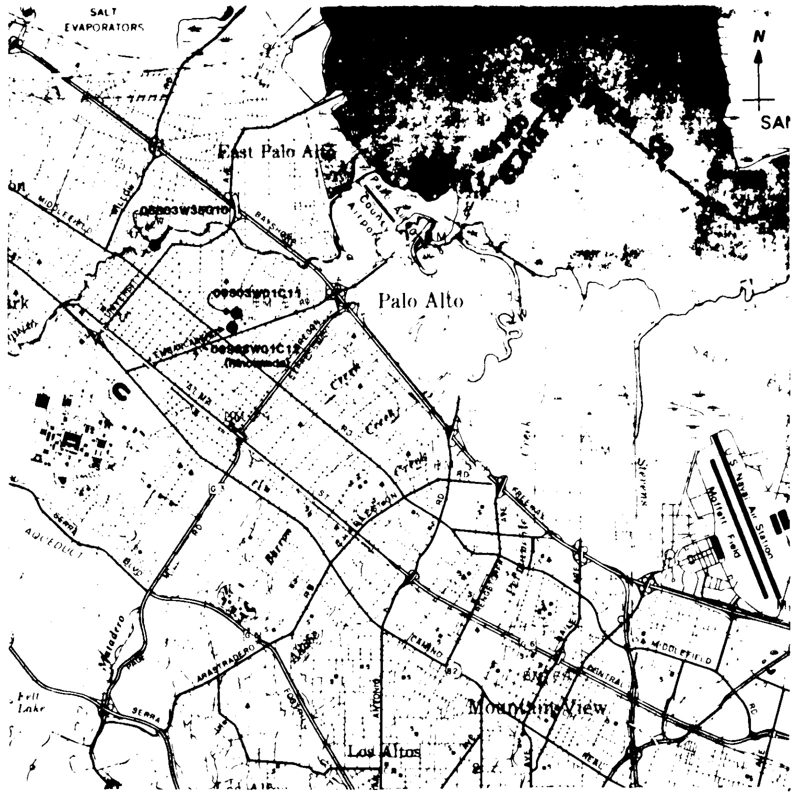
SEPTEMBER 1980

SCALE

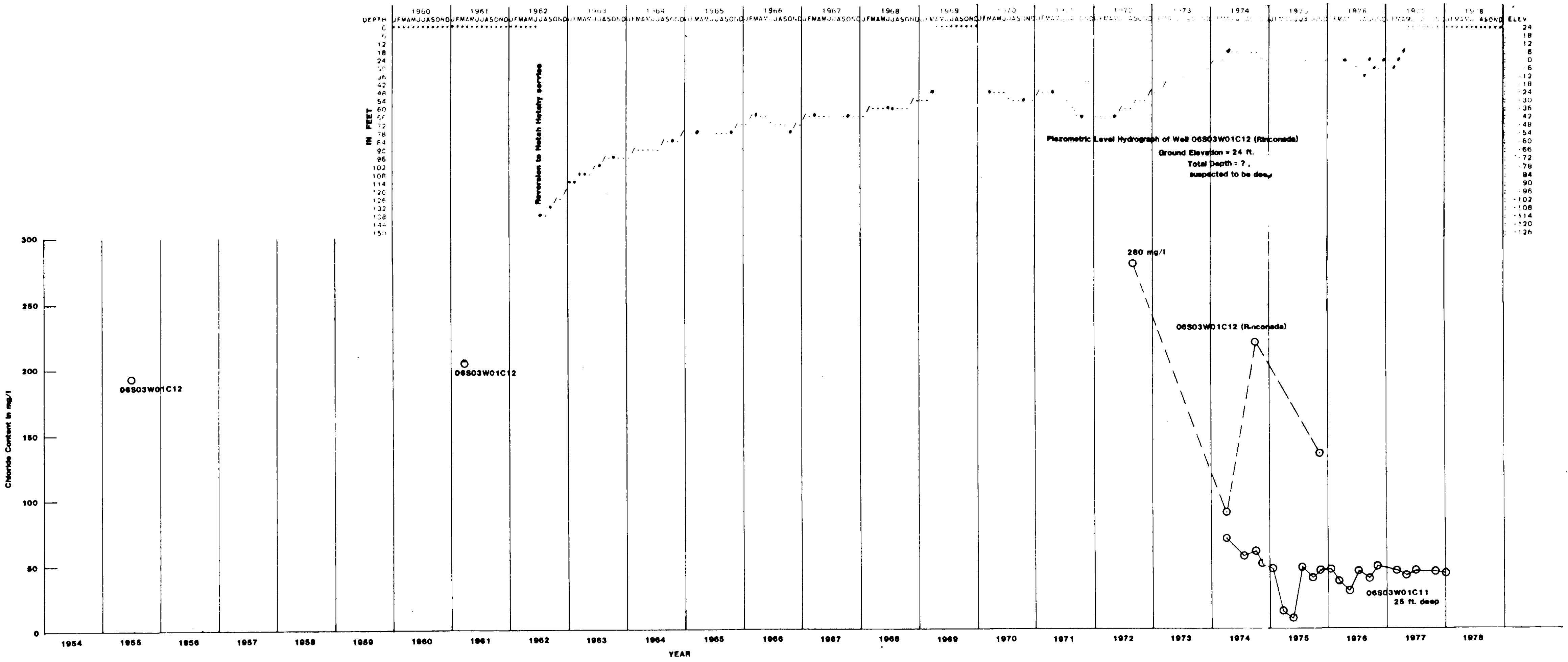
SHEET

PLATE 11





WELL LOCATION



REV	DESCRIPTION	DATE	APPR

REFERENCE INFORMATION AND NOTES

1. Represents selected examples ; limited by data availability.
2. Ground elevation of wells was approximated off U.S.G.S 7.5' quadrangle map and was not corrected for subsidence.

DATE
DESIGN
DRAWN
CHECKED

Santa Clara Valley Water District

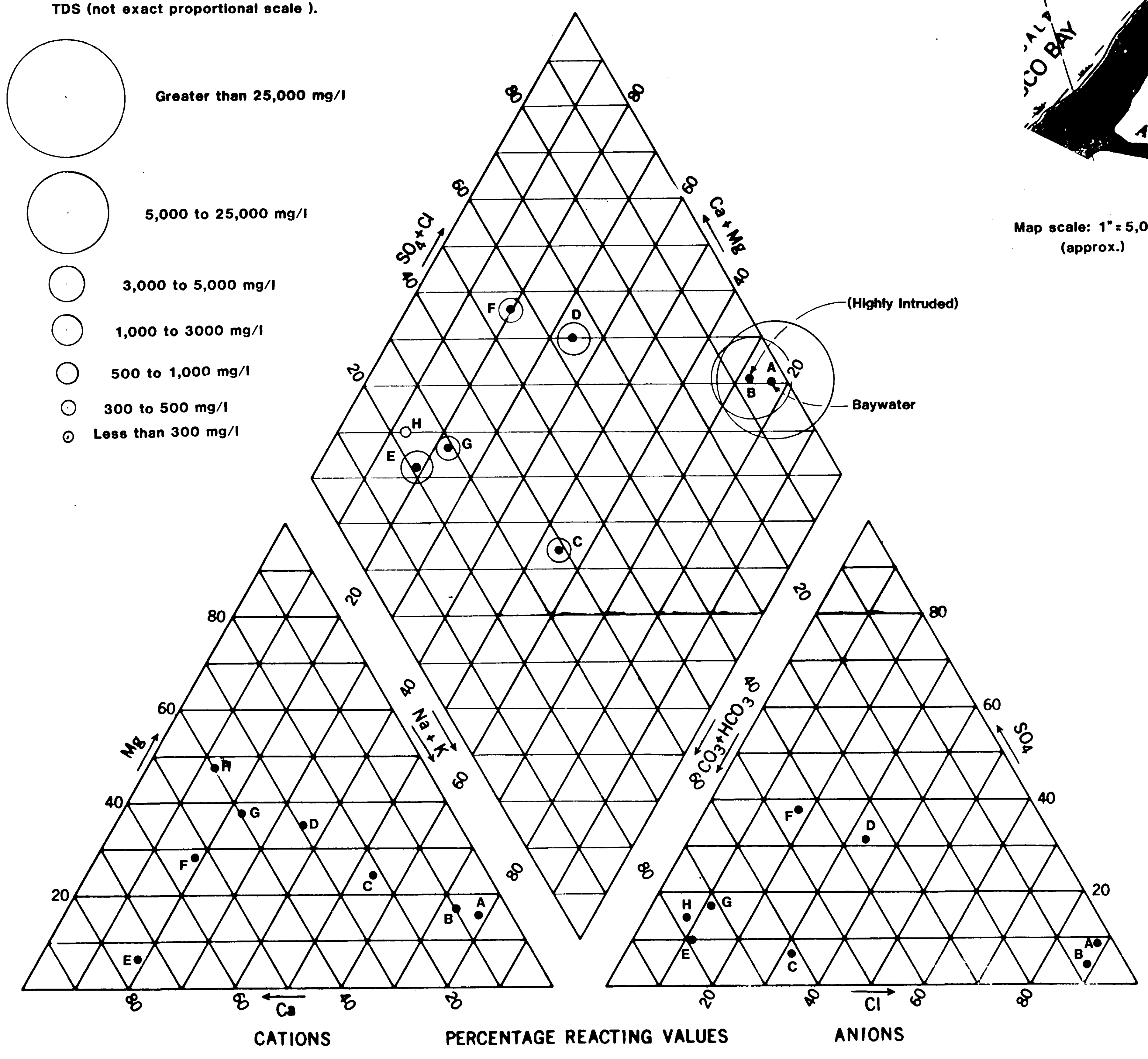
SALTWATER INTRUSION INVESTIGATION
SELECTED EXAMPLES OF TIME / CHLORIDE-CONTENT
AND WELL HYDROGRAPH PLOTS, LOWER AQUIFER ZONE,
PALO ALTO AREA

SEPTEMBER 1980

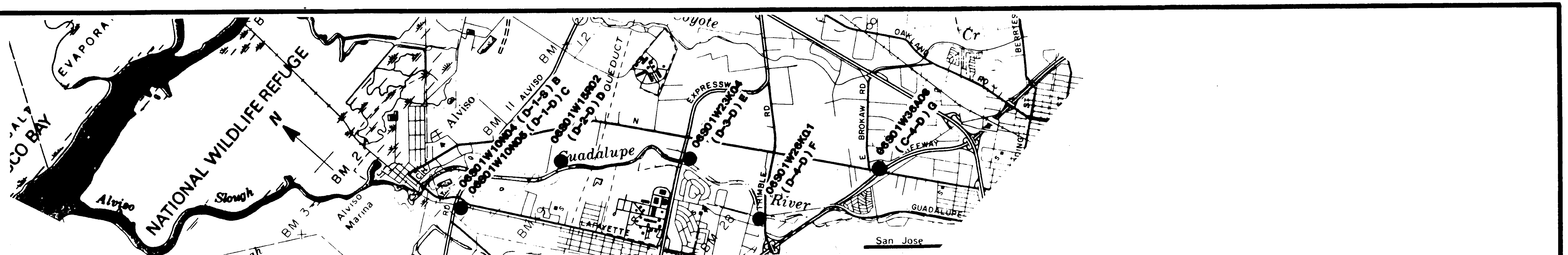
SCALE
SHEET

LEGEND

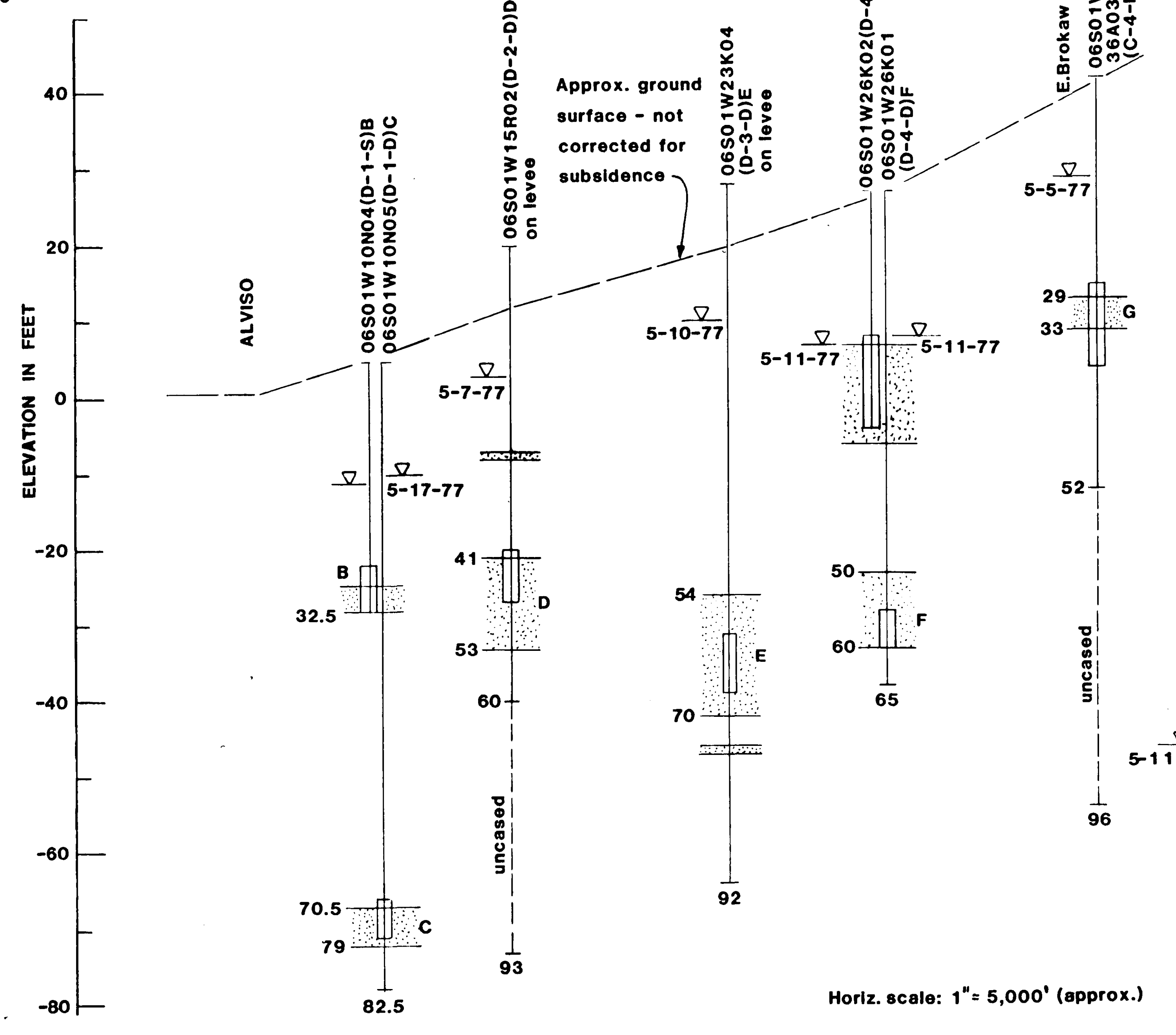
Area of circle denotes relative range of concentration, TDS (not exact proportional scale).



CATIONS PERCENTAGE REACTING VALUES ANIONS



Map scale: 1" = 5,000' (approx.)

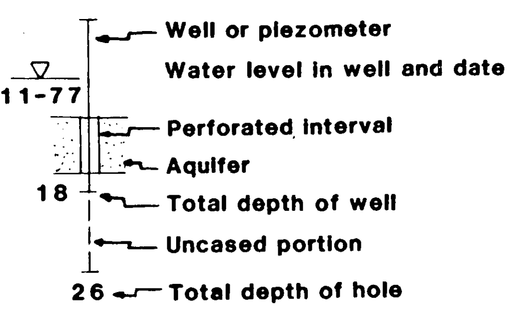


Horiz. scale: 1" = 5,000' (approx.)

SYMBOL	WELL NUMBER	OTHER NO.	DATE	WATER TYPE	TDS mg/l	EC µmhos/cm	CHLORIDE CONTENT mg/l
A	Baywater		10-58	NaCl	34,400	37,000	15,000
B	06S01W10N04	D-1-S	5-17-77	NaCl	12,140	20,160	7,250
C	06S01W10N05	D-1-D	5-17-77	$NaHCO_3$-Cl	802	1,288	163
D	06S01W15R02	D-2-D	5-17-77	Mixed	1,734	2,632	338
E	06S01W23K04	D-3-D	5-10-77	$CaHCO_3$*	2,408*	4,109 *	85
F	06S01W26K01	D-4-D	5-11-77	$CaHCO_3$-SO_4	824	1,270	79
G	06S01W36A03	C-4-D	5-5-77	Ca-$MgHCO_3$	618	865	38
H	Guadalupe Creek water at 08S01E19N		2-8-49	Mg-$CaHCO_3$		261	8

* Sample may be contaminated by cement annular well seal as pH was noted to be over 11.

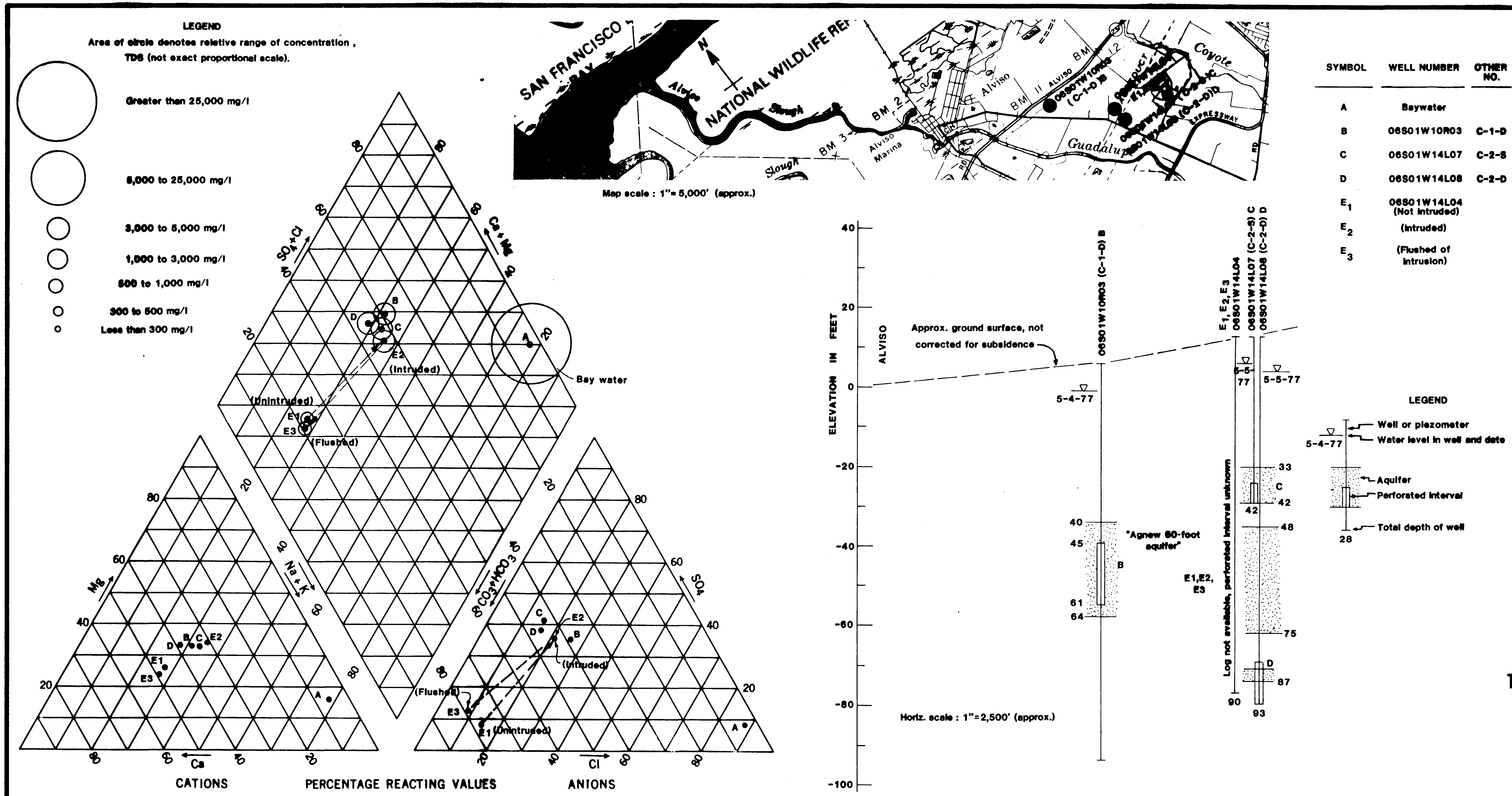
LEGEND



SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

TRILINEAR PLOT OF SELECTED WELL WATER SAMPLE ANALYSES, SOUTH OF ALVISO

SEPTEMBER 1980



SYMBOL	WELL NUMBER	OTHER NO.	DATE	WATER TYPE	TDS mg/l	EC µmhos/cm	CHLORIDE CONTENT mg/l
A	Baywater		10-58	NaCl	34,400	37,000	15,000
B	06S01W10R03	C-1-D	5-4-77	Mixed HCO_3-SO_4	864	1,703	163
C	06S01W14L07	C-2-S	5-5-77	Mixed HCO_3-SO_4	1,442	2,091	150
D	06S01W14L08	C-2-D	5-5-77	Mixed HCO_3-SO_4	1,222	1,845	127
E_1	06S01W14L04 (Not intruded)		8-12-54	$CaHCO_3$	331	494	18
E_2	(Intruded)		8-14-57	Mixed HCO_3-SO_4	1,110	1,740	139
E_3	(Flushed of intrusion)		8-30-60	$CaHCO_3$	320	513	18

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

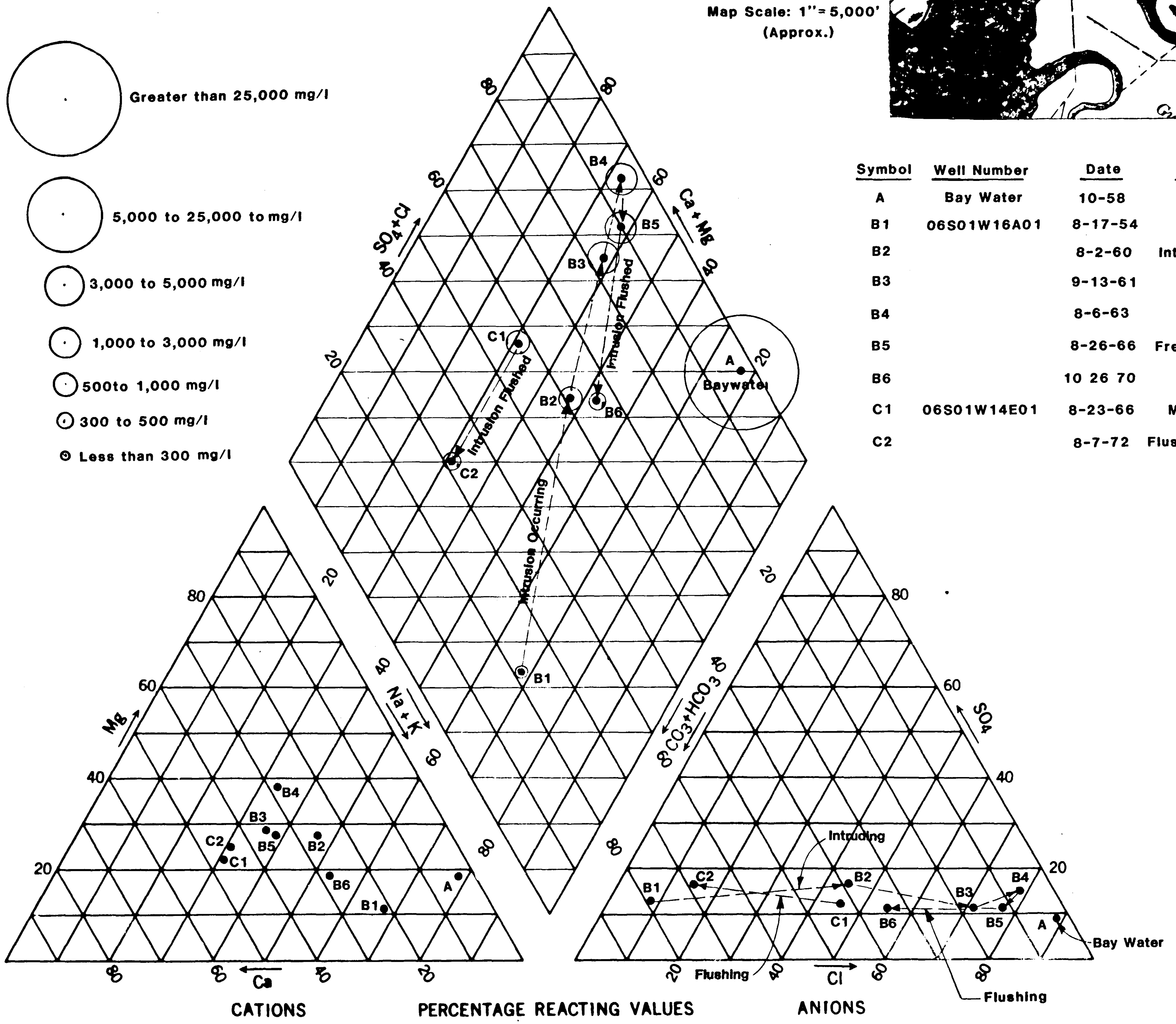
TRILINEAR PLOT OF SELECTED WELL WATER SAMPLE ANALYSES, SOUTH OF ALVISO

SEPTEMBER 1980

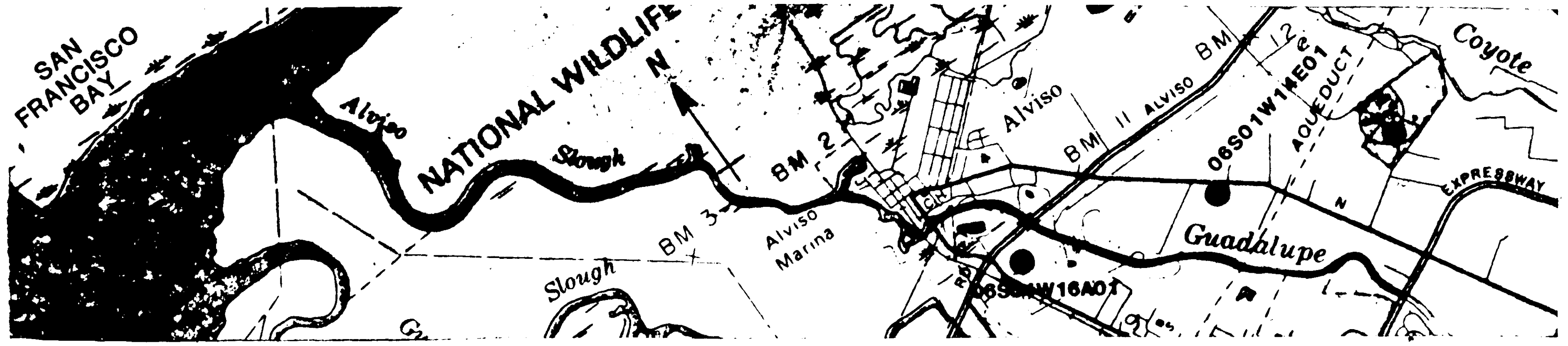
LEGEND

Area of circle denotes relative range of concentration
(Not exact proportional scale)

- ○ Greater than 25,000 mg/l
- ○ 5,000 to 25,000 to mg/l
- ○ 3,000 to 5,000 mg/l
- ○ 1,000 to 3,000 mg/l
- ○ 500to 1,000 mg/l
- ○ 300 to 500 mg/l
- ⊙ Less than 300 mg/l



Map Scale: 1"= 5,000'
(Approx.)



Symbol	Well Number	Date	Intrusion Status	Water Type	TDS mg/l	EC µmhos/cm	Chloride Content mg/l	Depth or Perforated Interval (ft.)
A	Bay Water	10-58		NaCl	34,400	37,000	15,000	
B1	06S01W16A01	8-17-54	Unintruded	$NaHCO_3$	284		14	Unknown,Prob. Composite
B2		8-2-60	Intrusion progressing	Na-MgCl-HCO_3	558		156	
B3		9-13-61	" "	Mixed Cation Cl	1,420		647	
B4		8-6-63	" "	"	2,450		1,080	
B5		8-26-66	Fresh Water flushing	"	1,460		690	
B6		10 26 70	" "	NaCl	550		203	
C1	06S01W14E01	8-23-66	Mildly intruded	Ca-$NaHCO_3$-Cl	536		138	Unknown,Prob. Lower Aquifer Zone
C2		8-7-72	Flushed by fresh water	Mixed HCO_3	412		40	

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

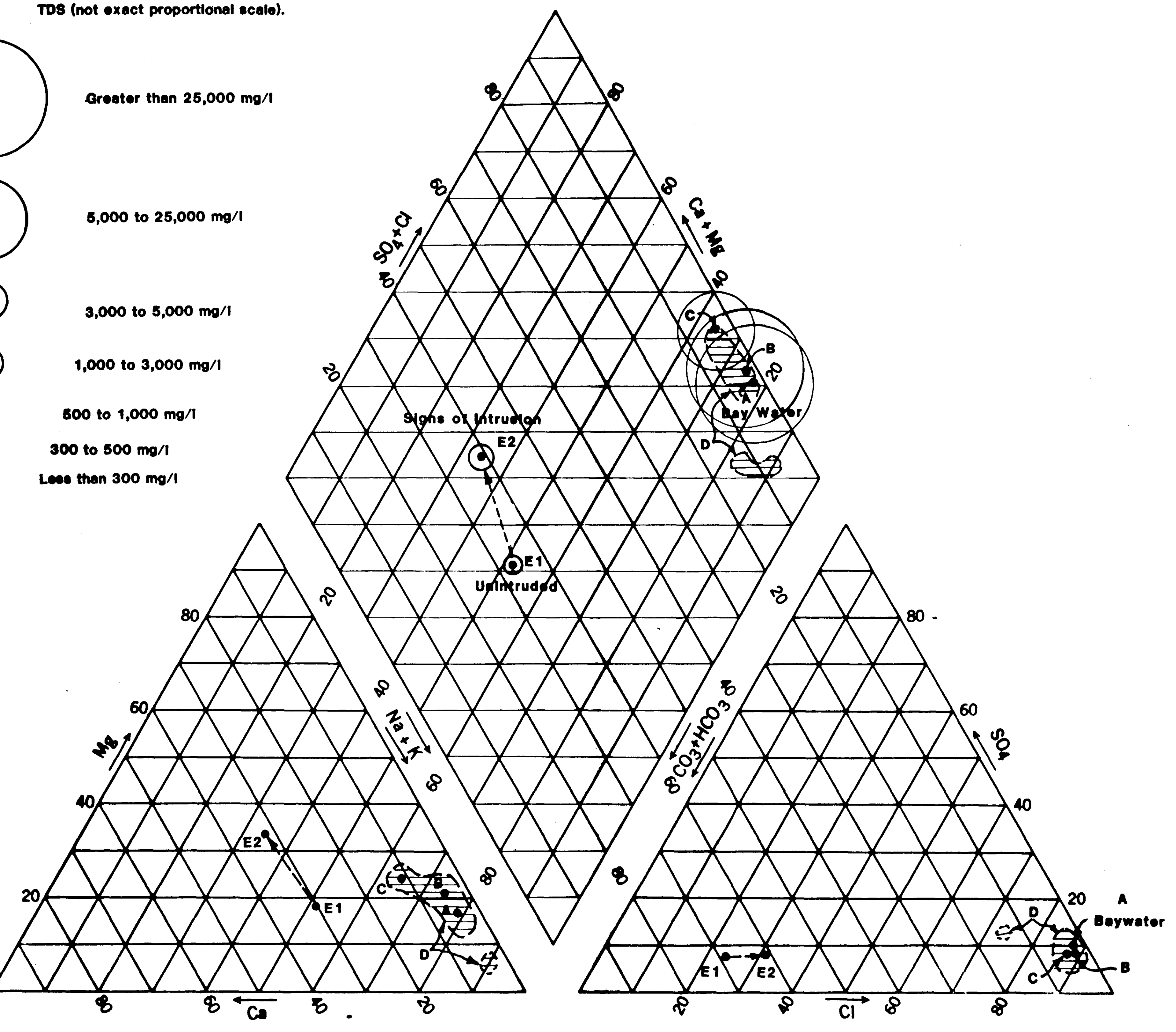
TRILINEAR PLOT OF SELECTED WELL WATER SAMPLE ANALYSES DEPICTING CHANGES IN PERCENTAGE REACTING VALUES, SOUTH OF ALVISO

SEPTEMBER 1980

LEGEND

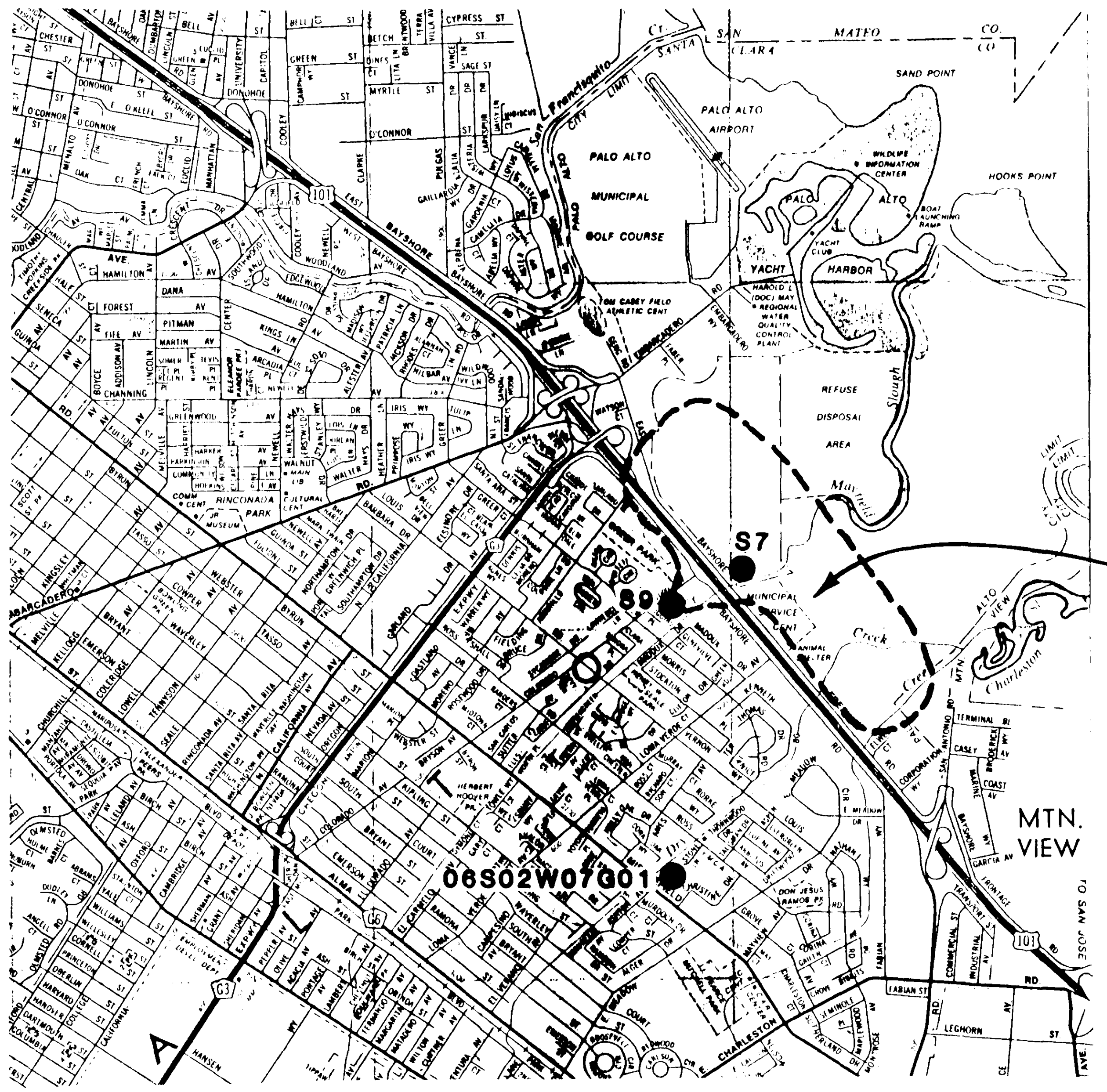
Area of circle denotes relative ranges of concentration, TDS (not exact proportional scale).

○	Greater than 25,000 mg/l
○	5,000 to 25,000 mg/l
○	3,000 to 5,000 mg/l
○	1,000 to 3,000 mg/l
○	500 to 1,000 mg/l
○	300 to 500 mg/l
●	Less than 300 mg/l



PERCENTAGE REACTING VALUES

SYMBOL	WELL NUMBER	OTHER NO.	DATE	WATER TYPE	TDS mg/l	EC µmhos/cm	CHLORIDE CONTENT mg/l	DEPTH OR PERFORATED INTERVAL (ft.)
A	Baywater		10-58	NaCl	34,400	37,000	15,000	
B	Unassigned	S-7	2-77	NaCl	82,144	106,000	41,400	36-39
C	Unassigned	S-9	2-77	NaCl	22,632	34,700	12,379	43-46
D	"D" denotes a general area on the trilinear plot of reacting values of 16 samples of the upper aquifer zone (depths of less than 100 feet) in the Palo Alto bayfront area. TDS ranged from 9,948 to 82,144 mg/l and chloride content from 4,660 to 41,400 mg/l. Included are samples "B" and "C". Concentration values indicate many of the samples far exceed that of baywater. All are sodium chloride type water.							
E_1	06S02W07G01		7-19-51	$NaHCO_3$	375	609	56	Probably lower aquifer zone
E_2	06S02W07G01		8-12-53	Mixed HCO_3	514	884	101	



Area where "D" samples obtained: is also site of injection-extraction hydraulic saltwater barrier project.

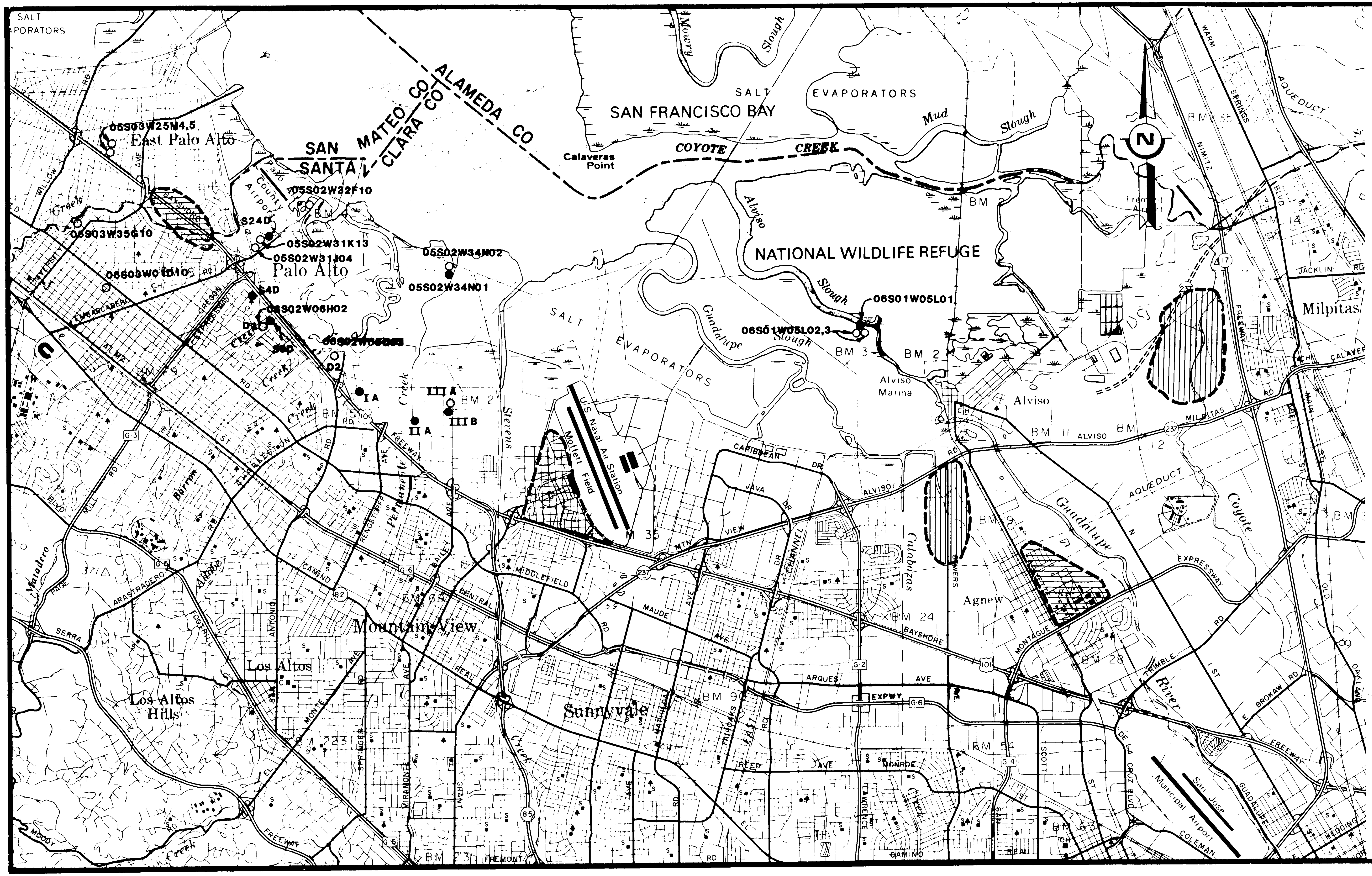
Map scale: 1" = 3,000' (approx.)

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

TRILINEAR PLOT OF SELECTED WELL WATER SAMPLES, PALO ALTO BAYFRONT AREA

SEPTEMBER 1980

PLATE 16



LEGEND

Recommended specific wells to be added to the salinity monitoring program:

- ● To monitor upper aquifer zone (0-150 ft. in depth)
- ○ To monitor lower aquifer zone (deeper than 150 ft.)

Recommend areas to be monitored but where a specific well has not been determined:

- ▤ For well to monitor upper aquifer zone.
- ▥ For well to monitor lower aquifer zone.
- ▦ For wells to monitor both upper and lower aquifer zones, respectively.

NOTES

1. Refer to Table 6 for well construction and other data for the specific recommended wells to be added to the salinity monitoring program.
2. Refer to Plate 6 for location of wells on the existing salinity monitoring program and Tables 3 and 5 for well construction data.

SANTA CLARA VALLEY WATER DISTRICT
SALTWATER INTRUSION INVESTIGATION

LOCATION MAP OF RECOMMENDED WELLS TO BE ADDED TO SALINITY MONITORING PROGRAM

SEPTEMBER 1980

SCALE : 1" = 5,000 ft.